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July 2012

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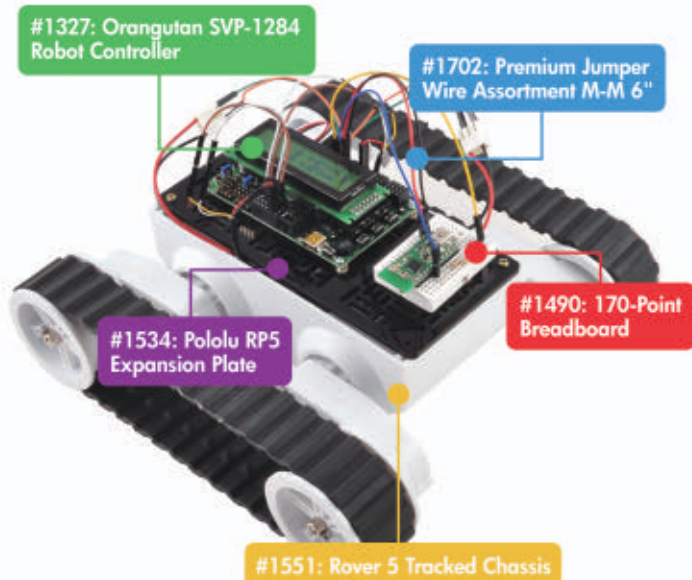
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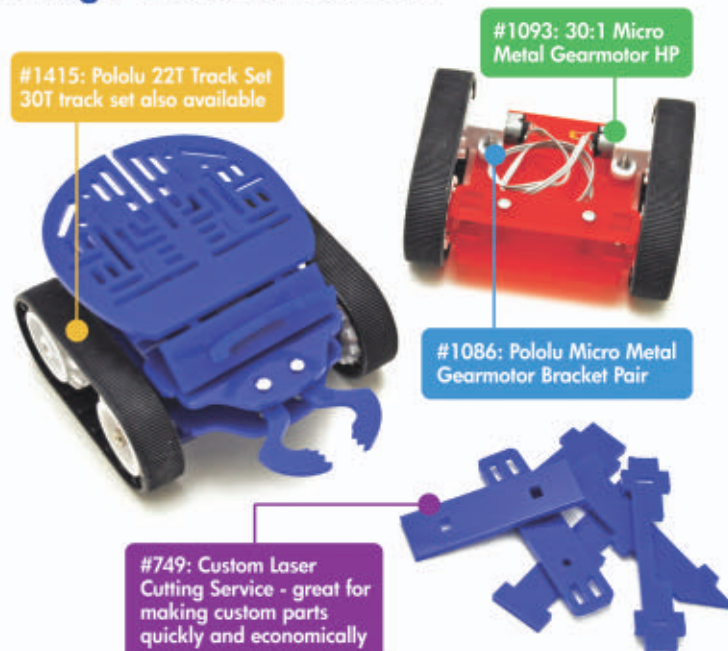


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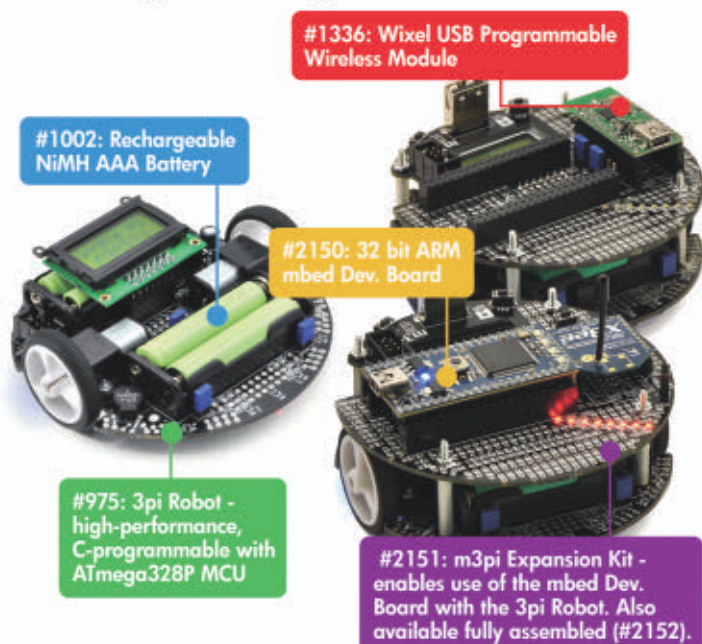
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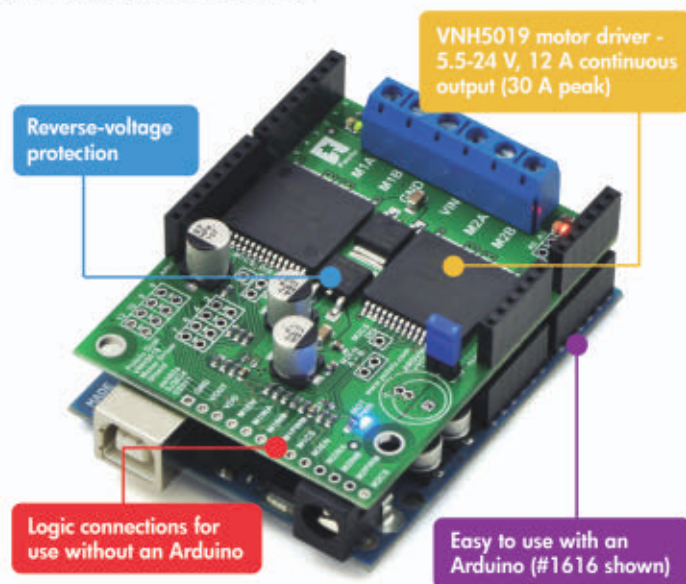
## Custom Laser Cutting: Design Your Own Chassis



## Robots and Robot Kits: Pololu 3pi and m3pi



## Motor Drivers: Item #2502: Dual VN5019 Motor Driver Shield for Arduino



Finding the right parts for your robot can be difficult, but you also don't want to spend all your time reinventing the wheel (or motor controller). That's where we come in: Pololu has the unique products - from actuators to wireless modules - that can help you take your robot from idea to reality.

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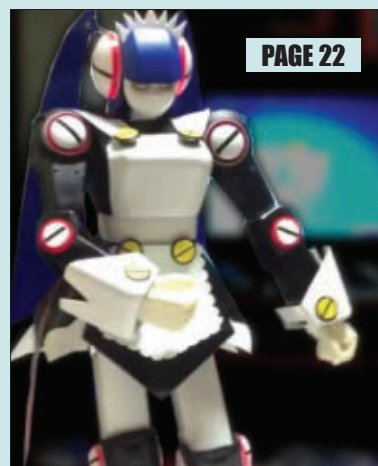
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Touch lets your bot determine its surroundings by making physical contact. Learn about a trio of common and inexpensive touch sensor types that you can add to your favorite automaton so it can get a sense of what's around it.

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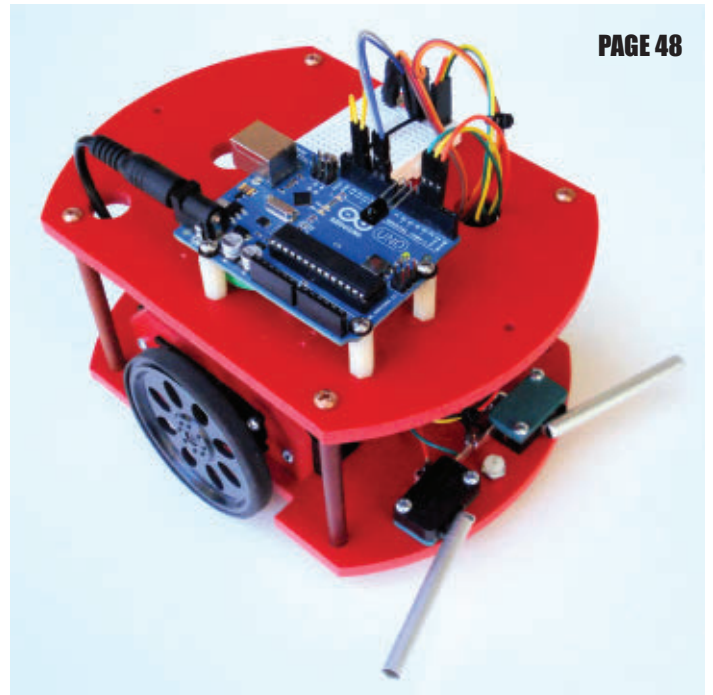
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In order for your robot to perform properly, it needs as much sensory data as possible. Unfortunately, physically increasing the number of sensors on your bot has potential problems. So, go virtual before completing your design.

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# Mind / Iron

by Bryan Bergeron, Editor

## Putting Robots to the Test

If you're a fan of *Blade Runner*, *Battle Star Galactica*, *Alien*, *Terminator*, or *Prometheus*, then you know that — at least for most people — the pinnacle of robotics is much more than a walking and talking tin can. The robots featured in these and other sci-fi classics certainly pass the Touring Test: a necessary but inadequate measure of how closely a robot resembles a human. Although not explicitly stated, these robots are physiologically correct — they breathe, bleed, and sweat as we do. Short of surgical exploration, the ultimate android is physically indistinguishable from a real human. This suggests the physical equivalent of the Touring Test for androids. I suggest the following test: *Allow a clinician to physically examine humanoid robots with the non-invasive instruments used for a traditional physical exam: a reflex hammer, blood pressure cuff, stethoscope, ophthalmoscope, and their hands — for 10 minutes. The clinician — without engaging in a conversation with the robot — must determine whether their patient is human, robot, or something in between.*

Because no human is perfect, this test suggests that the robot must exhibit some combination of normal and abnormal physical findings. Perhaps the robot's blood pressure is a bit elevated, there's a touch of asthmatic wheezing audible from the lungs, or there's a slight heart murmur.

So, if this is perfection in a physical sense, then how do we get from where we are now to the future of robotics? Science fiction writers and self-anointed futurists have the advantage of not having to create a detailed project plan for the realization of their visions. A more practical assessment of the trajectory of human-like robotics is to look at the progress in the development of human surrogates to train clinicians in both civilian and military scenarios. Task trainers — system-specific physical simulators — are increasingly used to train medics, nurses, and physicians on how to save lives and treat real patients. There are commercial and academic task trainers for applications ranging from learning to suture wounds, applying a tourniquet to stop massive bleeding, and interpreting heart and lung sounds to measure blood pressure, and delivering a baby.

Depending on the fidelity of these trainers and the availability of competing products, prices range from under \$100 to \$200K. Even at the upper price range, there is ample room for improvement. So, where to start?

I'd begin by reviewing the classic sci-fi films to decide what's a worthy goal. Superhuman strength or the ability to morph into another object or person probably shouldn't be at the top of your list. Take a rational assessment of your resources. Do you have a team of PhDs working for you or perhaps only a drawer full of servos and microcontroller boards? Assuming the latter, I'd start with something simple, such as replicating a basic reflex arc — think knee reflex.

If your neuromuscular system is normal, then when one of your tendons is suddenly stretched by someone else — say, by a nurse striking it with a rubber reflex hammer — then the muscle attached to the tendon will respond by quickly contracting. There is some value in this reflex if you examine what happens when you land after jumping down from a step stool. As you land, the tendon is suddenly stretched, signaling the muscle to contract, cushioning your landing. This unconscious reflex — which doesn't involve the higher centers of the brain — helps keep you upright and on your feet. (By the way, if you hit the tendon yourself or consciously focus on the reflex, you won't see it — do you know why?)

To replicate the basic tendon reflex, you don't need much more than a microcontroller, servo, and sensor. The sensor could be a commercial strain gauge or a piece of carbon-impregnated foam (the kind used to control static electricity). A sudden change in resistance for either one can be used to trigger

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the servo into action. While you're planning the next phase of your R&D toward a humanoid robot, a practical application is a self-righting reflex for a walker or crawler. Once you understand and apply the reflex arc, you can move to more complex physiology — from muscle strength and fatigue, to the complexities of the visual system. **SV**

## BIO-FEEDBACK

Dear *SERVO*:

Thanks for the great coverage in the April '12 issue in GeerHead. Unfortunately, my name was misspelled many times. It appeared as Valtrop, but the correct spelling is Veltrop.

**Taylor**

*Our apologies Taylor!*

Dear *SERVO*:

In the May '12 Twin Tweaks column, there is a reference to my having termed an OOPIC startup issue as a "cosmic wedgie." It's true that I used the phrase on a number of occasions while participating in the Yahoo! OOPIC group, but it was probably first coined by Dennis Clark — group moderator and author of *Programming and Customizing the OOPic Microcontroller*. I was just along for the ride, but thanks for remembering.

**Richard Stofer**

*Thanks for the clarification.*

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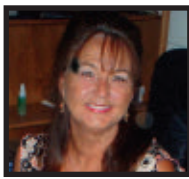


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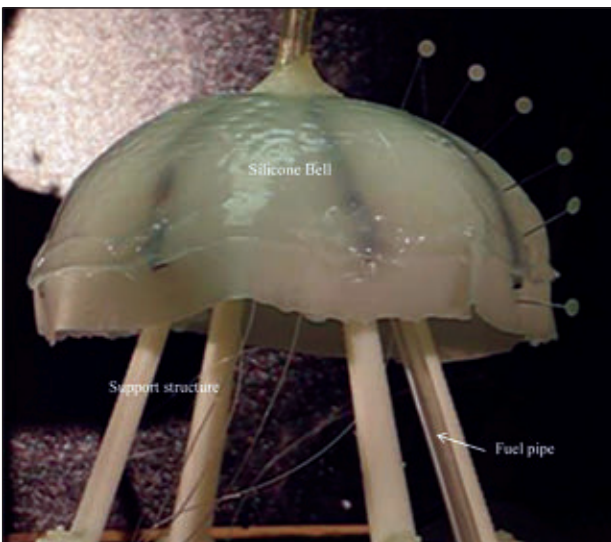


## UAV Bad News For Pirates

One of the military's meanest UAVs is the MQ-8B Fire Scout, built by Northrop Grumman Aerospace Systems ([www.as.northropgrumman.com](http://www.as.northropgrumman.com)). This robo-copter can be launched from any air-capable ship, as well as unprepared ground terrain, and it can lift up to 600 lb and operate at speeds exceeding 125 kt and altitudes up to 20,000 ft. Although it is typically fitted with various sensors to provide "situation awareness and precision targeting support" (e.g., detection of minefields, combat vehicles, and camouflaged targets), it can also be armed with smart bombs, missiles, and other projectile weapons. In April, the Office of Naval Research (ONR, [www.onr.navy.mil](http://www.onr.navy.mil)) announced preliminary tests of a Fire Scout fitted with its new Multi-Mode Sensor Seeker (MMSS), a mix of high-def cameras, IR sensors, and laser-radar (LADAR) technology. According to a program officer in ONR's Naval Air Warfare and Weapons Department, "Sailors who control robotic systems can become overloaded with data, often sifting through hours of streaming video searching for a single ship. The automatic target recognition software gives Fire Scout the ability to distinguish target boats in congested coastal waters using LADAR, and it sends that information to human operators who can then analyze those vessels in a 3D picture." A flight assessment will be conducted against groups of small boats in a military sea range off the California coast later this summer. If all goes as expected, piracy will soon be a much more dangerous business.



*Northrop Grumman's MQ-8B Fire Scout, to be fitted with a new package of sensors.*



*Robojelly propels itself via chemical reactions and shape memory alloys.*

## Jellyfish Runs On Hydrogen

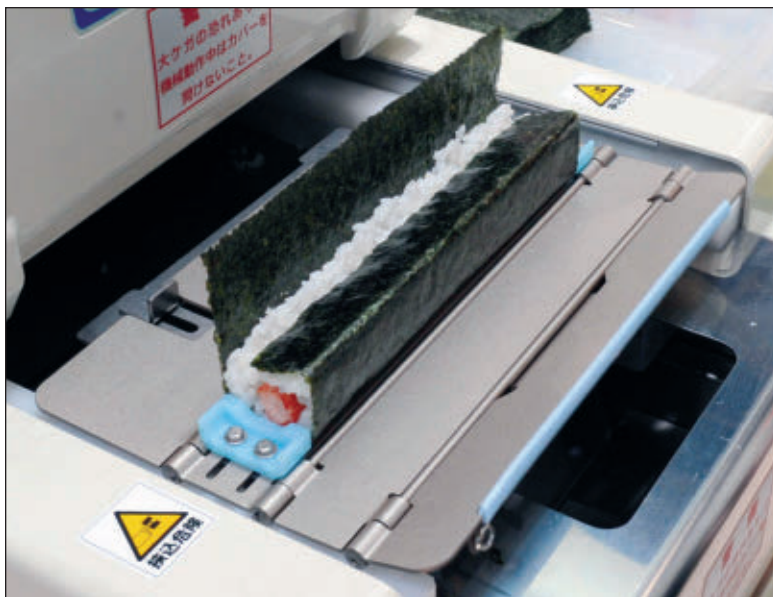
Much more benign is Robojelly — an ocean-going bot created at Virginia Tech ([www.vt.edu](http://www.vt.edu)) that was described in a recent issue of the journal *Smart Materials and Structures*. The device mimics a real jellyfish's rowing and jetting movements through the use of standard commercial shape memory alloys (SMAs) which are wrapped in carbon nanotubes and coated with a platinum black powder. Chemical reactions between the hydrogen and oxygen in the water and the platinum produce heat, which causes the SMAs to change shape and propel Robojelly through the water. The interesting aspect of this is that — at least in theory — the device should be able to operate indefinitely without refueling, as it uses the water around it for fuel. At present, the critter's eight bell segments operate simultaneously, so it can't be steered. However, a prospective version will allow selective delivery of "fuel" into each segment, so they can be controlled individually, thus allowing for movement in different directions. The developers suggest that Robojelly could eventually be used for underwater search and rescue operations, but it seems unlikely that it will

ever deliver much in the speed department. Also unanswered is the question of how to keep loggerhead turtles from mistaking them for the real thing, but I'm sure someone will think about that. There is, of course, a video viewable at [www.youtube.com/watch?v=U2OSJQHq8](http://www.youtube.com/watch?v=U2OSJQHq8).

## Automating Sushi

The big problem with sushi — aside from the somewhat revolting idea of putting things like raw eels into your mouth — is that making the stuff is highly labor-intensive. Sure, the Asian guy behind the counter at the restaurant is highly skilled and moves right along, but between his need to make a living and the cost of exotic seagoing creatures, sushi can be rather pricey. At the 2012 World Food and Beverage Great Expo, Japan's Suzumo Machinery Co. ([www.suzumokikou.com](http://www.suzumokikou.com)) recently demonstrated a sushibot that threatens to send our buddy Hiroshi to the unemployment lines. The company has actually been building sushi robots since 1981, but the latest version is a countertop machine that can crank out 300 medium-sized sushi rolls per hour, 24/7. According to the company, the bot is able "to precisely recreate the handmade taste and technique used by an experienced sushi chef."

Plus, the operator can set the roll's length and thickness, and produce them with inhuman precision and uniformity. Granted, it isn't as fascinating as watching a chef prepare them by hand (see [www.youtube.com/watch?v=QPPwXRZCqew](http://www.youtube.com/watch?v=QPPwXRZCqew)), but maybe the price advantage will allow a chain of McSushis to spring up around the country. And maybe not.



*Suzumo's sushibot generates up to 300 rolls per hour.*



*The EcoBot-III. When its mission is complete, it will die and gracefully decompose.*

after death." As a result, we will all sleep better in the knowledge that "hundreds or thousands" of robots can be deployed and disregarded with zero environmental impact. Except, of course, that they will probably smell even worse now. **SV**

## Old Robots Just Rot Away

In October 2010, we described the EcoBot-III, built by the Bristol Robotics Laboratory ([www.brl.ac.uk](http://www.brl.ac.uk)). The bot is a self-powered machine that actually eats, digests, and defecates (and reportedly smells really awful). Like the proverbial bad penny, it's in the news again as its creators — armed with a £200,000 (approx. \$325,000) research grant — now aim to add one more interesting attribute to the device: biodegradability. It's not immediately evident that the planet is littered with dead, discarded, and ecologically problematic robotic machinery, but Bristol's Dr. Jonathan Rossiter believes that "there is the ever-present risk that [a] robot will be irrecoverable with consequent damage to the ecosystem." He therefore aims to demonstrate that "soft robotic artificial organisms can exhibit an important characteristic of biological organisms: graceful decomposition

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by  
Dennis Clark

# ASK MR. ROBOTO

*This has been a light month for questions, so I'll answer one that I got and continue on with the saga of the Diligent MAX32 board. I've decided that I like this controller and PIC32 combination, and will be updating my Critter Crunch entry Silver Surfer with a new brain. My old controller board was one of my own from way back that was based on the Atmel ATMEGA8535 with a 754410 dual DC motor driver. I'll need a new motor driver, and these days there are a LOT more to choose from that are more robust than the venerable 754410 dual H-bridge (which dovetails nicely into one of the questions that I got this month). This is a BIG upgrade for Silver Surfer to an 80 MHz 32-bit micro from a 16 MHz eight-bit micro. I can hardly wait! My critter has to compete against humans in this competition (which is a bit of a challenge, let me tell you!). Anyway, on with the questions ...*

**Q** . I am interested in the motorization of a 600 g robot (two wheels + rolling ball); max speed 20 cm/sec. I am looking for the following: a set of brushless motors, wheels, and an I<sup>2</sup>C driven motor controller.  
— F. Saguez

**A** . The answer to your question is, "It depends." A 600 g robot will run handily on any motors that are in the torque range of about 2 Kg-cm to 3.5 Kg-cm. I'm assuming an indoor robot running on mostly flat surfaces like a floor or table. If you're going to be climbing steep inclines, then you'll want to use the higher torque motors; for flat surfaces, the lower end is fine. Now, about speed ... again, "It depends." This time, it depends on the wheel diameter as to how fast you will be moving. You can calculate the speed of your robot pretty simply by multiplying the wheel roll-out by the motor rotational velocity. Wheel roll-out is the distance that the wheel will cover in one revolution which is the perimeter of a circle, or  $\pi d$ , where  $d$  is the diameter of the wheel. So, if you want 20 cm/sec velocity and you have 5 cm wheels, then your

motor will need to spin at 1.27 RPS (Rotations Per Second), which is about 76 RPM (Rotations Per Minute).

You can tweak your speed by changing wheel diameters and/or motor voltage. You are not going to find brushless motors that spin that slowly. As a rule, the common brushless motor — even the high torque, lower speed outrunner type — will be spinning at over 10,000 RPM. If you gear them down to your 50-100 RPM range, you'll have WAY more torque than you'll need. I suggest that you stick with DC brushed motors.

To run those little motors, you want to use an I<sup>2</sup>C motor controller. That isn't so common since most of us just use H-bridges and drive them directly from our microcontrollers on such a small robot. However — while uncommon — I<sup>2</sup>C motor controllers are far from unheard of! A quick Google finds I<sup>2</sup>C controlled dual motor controllers at these three (well known) top hits:

[www.acroname.com](http://www.acroname.com)  
[www.robotshop.com](http://www.robotshop.com)  
[www.trossenrobotics.com](http://www.trossenrobotics.com)

At all of these sites, the price is under US\$100 for a dual motor controller; some are quite a bit under. There are no doubt more out there.

**Q** . (Reprise, part 33 and a third ... of the original question) I would like to see some of the more basic stuff with the chipKIT MAX32 such as utilizing the ADC with sensors, basic timer/interrupts, and the like. Also, I would like to see it interfaced with MPLAB utilizing C, instead of the Arduino processing structure.

**A** . Here is yet another installment of the continuing saga of the Diligent MAX32 board using the PIC32 microcontroller. I'm off and running ... we'll see how much I get done in the time that I have. This month, we're going to look at measuring distance with a sonar range finder. I've chosen an extremely inexpensive sonar unit: the

IC	Pin	Name	Connector silkscreen #
IC1	68	RD8	J8-48
IC2	69	RD9	J14-74
IC3	70	RD10	J8-38
IC4	71	RD11	J8-49
IC5	79	RD12	J3-8

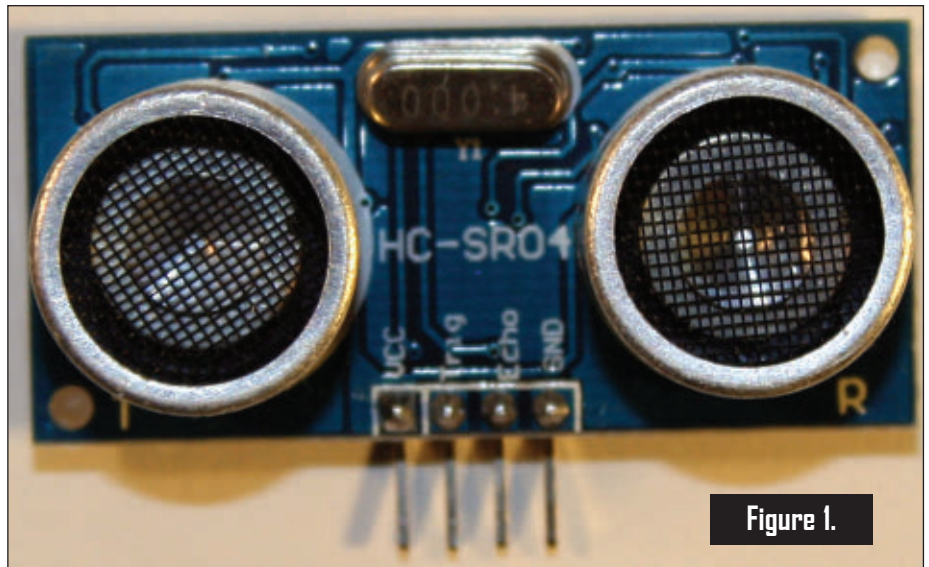
**Table 1. Input capture names, pins, connectors, and numbers.**

HC-SR04. I have no idea who makes this unit; just about everyone carries it at prices ranging from US\$8 to US\$15. The HC-SR04 has four pins: two for power, one to start the ping, and one to measure the pulse corresponding to the time-of-flight turnaround for the echo (see **Figure 1**).

To use the HC-SR04, you put a 10  $\mu$ S pulse out on the Trig pin (which is labeled on the board), and then time the duration that there is a positive pulse on the Echo pin. This time duration is the time-of-flight of the sonar's sound pulses out to an object and its return to the sensor. Remember that: It is the time *out and back*.

The key hardware block in the PIC32 that we will concern ourself with for this project is called the *Input Capture* block. While the overall specific datasheet for the PIC32MX795F512L discusses all of the hardware blocks and functions on the micro, you'll want to look at Microchip document "DS61122D: Section 15, Input Capture" for details about this block that you might not find in the main datasheet. Studying this document will help you to understand the settings used in the "PIC32 Peripheral Libraries for MPLAB C32 Compiler; Section 12.0 Input Capture Functions" which is what I'm going to use to work our sonar.

This PIC32 variant has five IC (Input Capture) pins; see **Table 1** for their names and pin numbers. For my tests, I'm going to use IC1 because I found it first. Hunting down what pin is what and where it goes is tedious. Remember



**Figure 1.**

that our pins are labeled by everything that they do, so search for the pin IC1 on the chip pin layout for the 100-pin TQFP part and you'll find it. I also found the pin number and the connector number for the I/O line on the MAX32 schematic document that you can get from the Digilent site ([www.digilentinc.com](http://www.digilentinc.com)). Note that these pins are in no particular grouping or order.

We can choose between two 16-bit timers (TIMER2 and TIMER3) or combine them as a single 32-bit timer. I think that a 16-bit timer is good enough; we'll use TIMER3.

The HC-SR04 says that the range of values for the echo pulse is 150  $\mu$ S to 25 ms with a 38 ms pulse, meaning that nothing was in range. So, we need our 16-bit timer to give us a maximum reading of 38 ms. We'll divide 38 ms by 65536 to find out what each tic of the clock will need to be. This comes out to be about 580 ns (nano seconds). We have timer pre-scale options of 1, 2, 4, 8, 16, 32, and 256. If we divide our 10 MHz clock by 8, we get 1.25 MHz which is 800 ns. Multiply this by 65536 and we have a full scale timing of 52.429 ms. That's close enough for me. A 150  $\mu$ S reading would then be 150  $\mu$ S/800 ns = 187.5 or 187, which is pretty reasonable resolution. The 25 ms max

## Listing 1: Configure the IC hardware to measure a pulse.

```

/* Set TIMER3 for our Input compare work
* Turn T3 on
* User internal 10MHz peripheral clock
* Prescale by 8, gives 1.25MHz for a 52.429ms full scale
* 0xFFFF, use the whole thing (really only need 38ms...)
*/
OpenTimer3(T3_ON | T3_SOURCE_INT | T3_PS_1_8, 0xFFFF);

/* Configure IC1 to measure a pulse
* Enable Input Capture Module 1
* Capture Every edge
* Enable capture interrupts
* Use Timer 3 source
* Capture rising edge first
*/
OpenCapture1(IC EVERY_EDGE | IC_INT_1CAPTURE | IC_TIMER3_SRC | IC_FEDGE_RISE | IC_ON);

// Set RF1 as an output to trigger the SONAR, clear the pin for now
PORTCclearPinsDigitalOut(IOPORT_F,BIT_1);

```

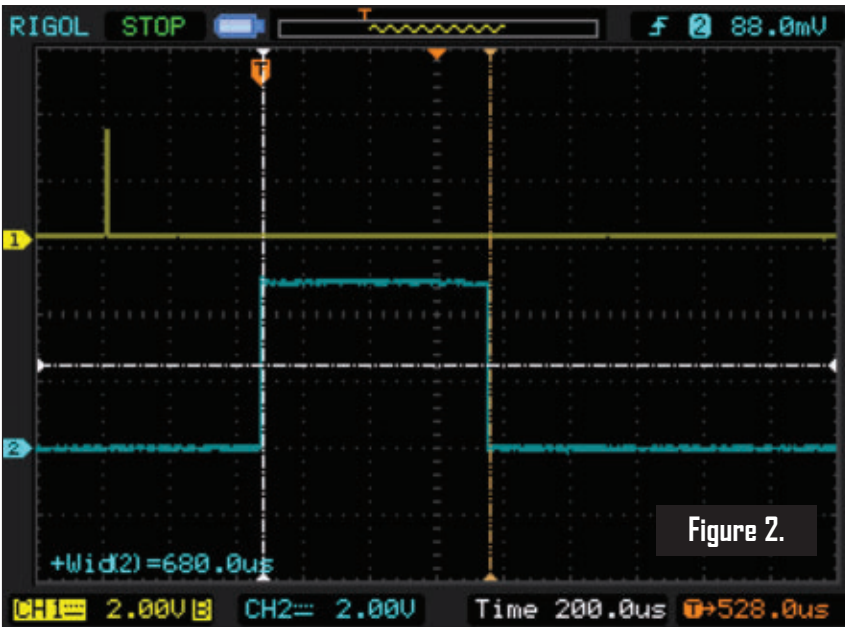


Figure 2.

range is  $25 \text{ ms} / 800 \text{ ns} = 31,250$ . That'll do.

We want our hardware to do all the heavy lifting for us. That is why we're going to use the Input Compare block, IC1. There are a LOT of options here, but we're concerned with setting which timer we'll be using and how the pulse looks that we're measuring. **Listing 1** shows

how we set our TIMER3 and IC1 hardware blocks up.

Finally, we set up an I/O pin to use as the trigger for the sonar.

The whole program is pretty simple to handle this job. At the article link, you'll find a zip file called [robotojuly.zip](#).

The speed of sound is about  $340 \text{ m/s}$ . I want to have centimeters though, so that is  $34,000 \text{ cm/s}$ . For those of you that like English units, that would be about  $13,386 \text{ in/s}$ . Those are big numbers, and I hate to deal with fractions in embedded code. So, if we do some math adjustments, we can get a simple divisor for range numbers. With that in mind, our IC value will be ticks on the clock. We set our TIMER3 to be  $800 \text{ ns}$  per tick. So, check this out:

```
cm = tics * 34000 * 800ns,
multiply this and we get cm = tics/37
in = tics * 13386 * 800ns, which ends up in
= tics/93
```

All I did here was combine all of the constants, and rounded up for an integer value.

This gets us close, but I discovered that the rising edge of the echo line always occurred  $450 \mu\text{s}$  after the trigger started. A trigger pulse is eight  $40 \text{ kHz}$  pulses, which takes  $200 \mu\text{s}$ . If we assume that we won't get an echo back until after that  $200 \mu\text{s}$  worth of pulses goes out, then we can start our distance timing at the end of that  $200 \mu\text{s}$ . To improve our close-in accuracy, we will subtract that  $200 \mu\text{s}$  by subtracting  $250$  ( $200 \mu\text{s} / 800 \text{ ns}$ ) from the last pulse measurement. Because we lose another  $250 \mu\text{s}$  in what is usually called damping time on our sonar, this means that the closest measurement that we can take is about  $7.6 \text{ cm}$ , or three inches. So, with all this in mind, here are our final range formulae:

```
cm = (t[1]-250)/37/2;
in = (t[1]-250)/93/2;
```

We divide by 2 because this time is out and back, and we only want half of that to get our range. **Figure 2** shows a scope trace of a sonar ping session.

I couldn't find a graceful way to show range by blinking an LED, so I commented one line as the place to put a break point to see the values of the cm and in variables in the code.

Well, another month has gone by. I hope to figure out how to create a program that will use the Arduino bootloader in the future. That would make things really easy to deal with! Until next month, please let me know what is on your mind and I'll do my best to help you with it. You can contact me at [roboto@servomagazine.com](mailto:roboto@servomagazine.com) to ask me any question about robotics that you have. **SV**

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- **Input Voltage** : 7.4V DC (DRS-0101) / 7~12V DC (Optimized 7.4V) (DRS-0201)
- **Stall Torque** : 12kgf.cm@7.4V (DRS-0101) / 24kgf.cm@7.4V (DRS-0201)  
[ 166.8 ozf.in. (DRS-0101) / 333.6 ozf.in. (DRS-0201) ]
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# GEER HEAD

by David Geer

Contact the author at [geercom@windstream.net](mailto:geercom@windstream.net)

Discuss this article in the  
SERVO Magazine forums at  
<http://forum.servomagazine.com>

## Count on the ARTAS System For That New Head of Hair!

When hereditary or male pattern baldness strikes, who you gunna call? A surgeon using the ARTAS System for robotic hair restoration surgery, that's who!

The FDA cleared the ARTAS System for hair replenishment duty as of Spring 2011. With national rollout of the device in full swing, there are already major hair restoration services regularly using the technology in New York, Los Angeles, Dallas, and Denver.

The precision of the robotic arm makes hair restoration surgery much more accurate and much less invasive. It also cuts down surgeon fatigue, which helps eliminate potential surgical errors.



The complete ARTAS System for hair restoration surgery.

**This patient is ready for action — prior to hair restoration surgery — under the advanced ARTAS robotic surgical arm and the guidance of a capable surgeon, who has mapped out an area of the scalp above the neck for harvesting. Soon the surgeon will implant the hair in the scalp above the forehead.**

## Robotic Follicle Harvesting

The Mountain View, CA company Restoration Robotics' ARTAS System is a computer-assisted technology that is interactive with the live surgeon in the room. The robotic arm — guided by images — does a measurably improved job of hair follicle harvesting prior to hair reinsertion.

The robotic system enables surgeons to achieve higher accuracy in the art of FUE (Follicular Unit Extraction) surgical techniques, stabilizing the procedure for consistently high quality results.

The ARTAS System uses a combination of robotic and computer technologies from various fields including robotics, image guidance, machine vision, force control, visual servoing (it dynamically adjusts to patient movement), and an advanced user interface.

The ARTAS System is safe for delicate hair transplant surgery (since it is near the brain, after all) because it is designed to be immobile unless a signal from the camera system tells the robot to move.

"The camera system sends a signal to the robot so it can move only after it visualizes multiple hair follicles and verifies the distance between the needle and these hair follicles," according to Restoration Robotics. The image guidance system then deploys the needle mechanism and positions the needle safely and accurately near the follicular unit it is about to harvest.

The system commands the robot arm to stop moving before the follicular harvesting so that the arm does not contribute to any errors. The sharp inner needle then enters the skin about 1 to 2 mm. The dull outer punch rotates and advances forward into the skin. It is set for a hard stop at 4 mm; the punch cannot enter the skin beyond 4 mm. The scalp is (usually) more than 1 cm thick.

## Sensors Enable Safe ARTAS Use

There are redundant safety features in the ARTAS System. A six-axis force sensor between the robot flange



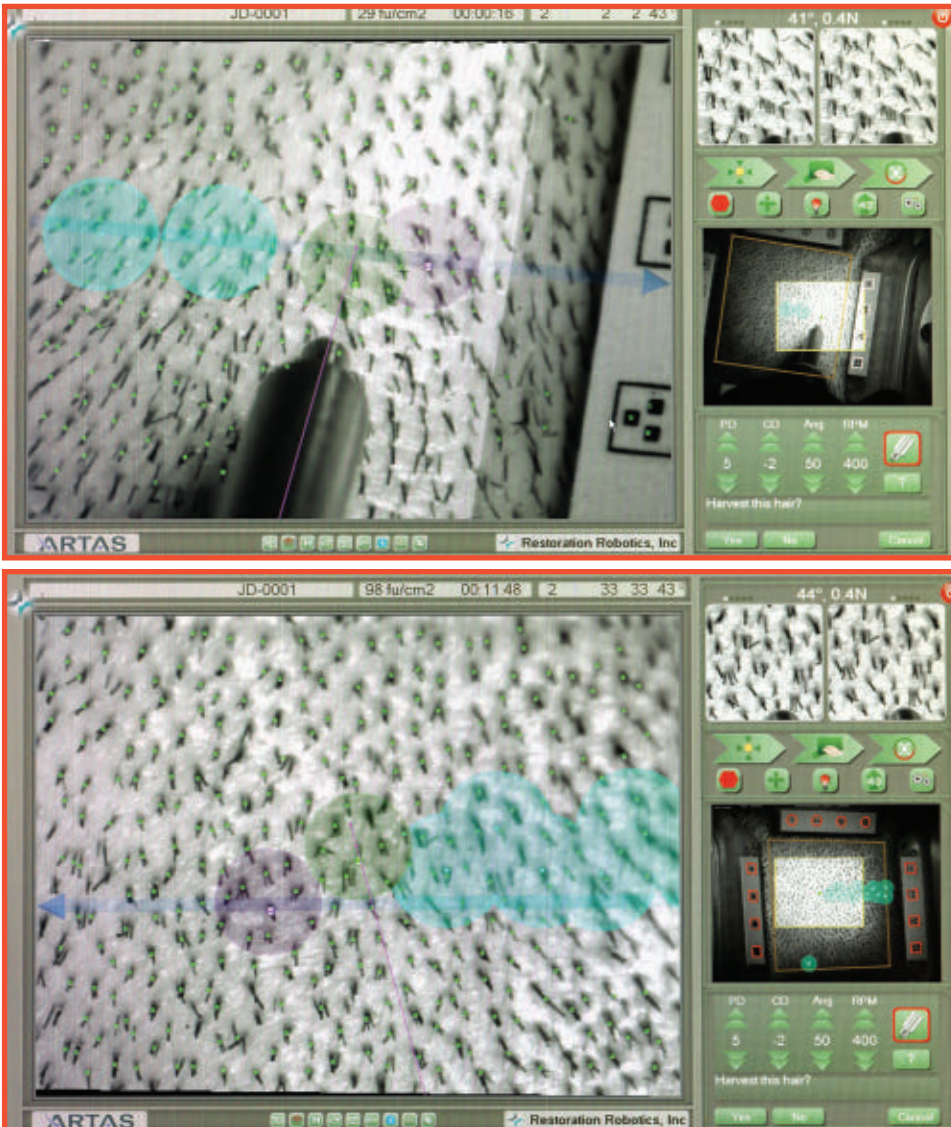
and the needle mechanism senses any excessive force on the needle mechanism, triggering an immediate emergency stop. This cuts power to all motors and valves, retracting the needle away from the patient, as explained by Restoration Robotics. The force sensor measures all forces on the entire mechanism and any collisions with the ARTAS cart, chair, or other objects, protecting the operator (surgeon). The unit also has multiple emergency stop buttons for the surgeon's own initiation of a full stop.

The robot performs all its movements in Velocity mode. The cameras monitor the desired follicular unit and calculate the relative distance and orientation with respect to the position of the needle. The robot uses three translational and three rotational velocities to move itself. The robot modulates these velocities after it takes each new image and determines the relative location of the follicular unit with respect to the needle.

The new relative position will include robot movements, as well as patient movements (if any). In the present system, the images are being acquired at a rate of 50 times per second. Therefore, the velocity commands are updated at 50 times per second which will result in smooth movement of the robot while continuously compensating for patient movement.

## The Image Guided Robotic Arm and Image Processing

The image guided robotic arm continuously monitors follicular units and tracks the ones it desires, one at a time. Once the robot accurately positions the needle mechanism



**The ARTAS System hair restoration technology as seen at the end of the surgical arm.**

The image system tags each individual follicular unit with a unique identifier to track it from image to image, even as it streams new images from the camera. As the patient (as well as the robot) is moving, this tracking step is not trivial. There are more than 200 follicular units that the robot tracks over a period of time. The robot performs all these steps within 10 ms of computation time on the computer, according to the company.

Once the robot harvests a follicle, a computer algorithm analyzes it and selects the next follicular unit (as opposed to having a pre-selected pattern of follicular units) based on certain heuristics. This approach results in a random pattern of harvests which, in turn, results in unnoticeable harvesting in the donor area.

## The Computer Interface and the Programming

over the desired follicular unit, the robot arm stops and actuates its needle and punch mechanism to dissect the tissue while continuously applying vacuum suction through the needle. After harvesting, the robotic arm tracks the next follicular unit and the process repeats itself until a set number of units are harvested.

The robotic arm can determine whether the hair follicle has one, two, three, or four hairs, repeat the harvesting process without the fatigue a surgeon working alone might experience, and work consistently from patient to patient.

The arm's advanced proprietary imaging technologies can tell the location, angle, and direction of every follicular unit of scalp within the camera's field of view. The camera can see 200 or more follicular units per patient. The image processing automatically segments each follicle between the left and right views automatically. It then identifies the follicular units in each view in a step called pairing. The image processing technology calculates 3D information about the paired segments.

The ARTAS System's computer interface consists of a Graphical User Interface (GUI) which the surgeon can interact with using a mouse and keyboard. This interaction is typically for giving commands such as begin harvesting or cancel harvesting, or for adjusting certain parameters such as an increase in the depths of harvesting, or for adjusting the selection process.

Restoration Robotics uses a standard PC loaded with the Microsoft Windows 7 operating system. They use Visual Studio for program development and C++ and C# as needed on the PC side. On the robot side, the programming is done in Staubli robot's supported language Val3. There is also firmware in the needle mechanism that is developed using the C programming language.

Restoration Robotics employs C# primarily for the user interfaces. The company uses the C++ language for all the other programming. The company's programmers use OpenGL, as well as Direct X for advanced computer graphics. The organization develops most of the imaging algorithms in-house while using an OpenCV library.

## Interactivity

While the ARTAS System is highly automated, it is also very interactive. The surgeon can interact with the system while it is performing the automated harvesting. For example, the surgeon can select a follicular unit for harvest with the mouse by simply clicking on the screen; the automation algorithms understand and harvest the selection.

Similarly, the surgeon can pause and resume the harvesting at will, and adjust the parameters (such as depths and angles) at any time. The surgeon can even move the robotic arm to the patient initially by putting the robot into "Force Drag" mode, and pushing the robot towards the patient.

Two lasers that are part of the mechanism shine on the patient, and when they come together it means the needle mechanism is positioned such that the patient's scalp is in focus for the camera.

## The Needles

The sharp inner needle has a bi-bevel tip. The robot actuates the needle at a high speed pneumatically as it enters the skin superficially. The bi-bevel tip allows it to puncture the skin without sliding or allowing any transections. Since it travels at a high velocity, the patient does not have time to move away. The inside diameter of the inner needle is 1 mm. Therefore, the defect in the skin it creates is 1 mm in diameter.

The dull outer punch rotates (typically at 400 to 800 rpm) and enters the skin at slow linear speeds. This enables the dull punch to dilate a 1 mm diameter defect created by the inner needle. The punch travels past the inner needle performing the dull dissection. Since the punch is dull, it pushes more than it cuts; therefore, it avoids any possible transections even if the follicle curves under the skin.

## Conclusion

After the procedure, most patients return to normal activities within a day or two. By nine months after the harvesting, they are experiencing full natural looking hair that lasts a lifetime.

The ARTAS System is a fitting addition to the surgical robot market, where surgical robots will soon be multiplying like hares ... er, uh rabbits. **SV**

## Resources

Restoration Robotics, creators of ARTAS  
[www.restorationrobotics.com](http://www.restorationrobotics.com).

ARTAS technology  
[www.restorationrobotics.com/rr\\_technology.html](http://www.restorationrobotics.com/rr_technology.html)



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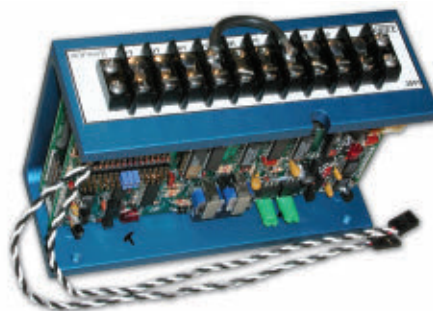
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# EVENTS

# Calendar

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Send updates, new listings, corrections, complaints, and suggestions to: [steve@ncc.com](mailto:steve@ncc.com) or FAX 972-404-0269

Know of any robot competitions I've missed? Is your local school or robot group planning a contest? Send an email to [steve@ncc.com](mailto:steve@ncc.com) and tell me about it. Be sure to include the date and location of your contest. If you have a website with contest info, send along the URL as well, so we can tell everyone else about it.

For last-minute updates and changes, you can always find the most recent version of the Robot Competition FAQ at Robots.net: <http://robots.net/rcfaq.html>.

— R. Steven Rainwater

## JULY

### 3-6 International Micro Air Vehicle Competition

*Braunschweig, Germany*

Various events for autonomous and remote control flying micro-robots.

[www.imav2012.org](http://www.imav2012.org)

### 7 RoboBombeiro

*San Miguel Pavillion, Guarda, Portugal*

Autonomous fire fighting robots.

<http://robobombeiro.ipg.pt>

### 10-15 WCCI Competition

*Brisbane, Australia*

Events include Human-like Bots, Physical Traveling Salesman Problem, and the Turing Test Track.

[www.wcci2010.org](http://www.wcci2010.org)

### 17-22 International RoboSub Competition

*SSC Pacific TRANSDEC, San Diego, CA*

Student teams build autonomous robot subs to accomplish a mission that's different each year.

[www.robosub.org](http://www.robosub.org)

### 18-22 Botball National Tournament

*Honolulu, HI*

Student teams build autonomous robots that move black and white balls around on a game board.

[www.botball.org](http://www.botball.org)

### 22-26 AAI Mobile Robot Competition

*Toronto, Ontario, Canada*

Different mobile robot contest events each year.

[www.aaai.org/Conferences/AAAI/aaai12.php](http://www.aaai.org/Conferences/AAAI/aaai12.php)

23-27

### K\*bot World Championships

*Las Vegas, NV*

Student-built robots compete in autonomous and remote control divisions.

[www.kbotworld.com](http://www.kbotworld.com)

29

### ASABE Robotics Competition

*Dallas, TX*

Student-built agricultural robots compete on a cattle feedlot course. Contest runs through August 1.

<http://abe-research.illinois.edu/ASABERobotics>

31

### AUVS International Aerial Robotics Competition

*Betty Engelstad Sioux Center, UND  
Grand Forks, ND*

University teams build flying autonomous robots and sub-vehicles that compete in a task that varies each year.

<http://iarc.angel-strike.com>

## AUGUST

4

### Chibots SRS Robo-Magellan

*Moraine Valley Community College, Palos Hills, IL*

Autonomous robots compete on an outdoor course that requires waypoint navigation and vision.

[www.chibots.org](http://www.chibots.org)

9-19

### Missouri State Fair Robot Expo

*Sedalia, MO*

Various robot events including the 4-H Show-Me Robotics Competition. Check the Fair schedule for exact days and times of each event.

[www.mostatefair.com/special-events](http://www.mostatefair.com/special-events)

20-25

### FIRA Robot World Cup

*Bristol, England*

All the usual autonomous robot soccer divisions, ranging from tiny robots up to humanoid bots.

[www.fira.net](http://www.fira.net)

31

### DragonCon Robot Battles

*Atlanta, GA*

Remote controlled vehicles destroy each other at the DragonCon science fiction convention.  
[www.dragoncon.org](http://www.dragoncon.org)

## SEPTEMBER

- 3-8** **National Junior Robotics Competition**  
*Science Centre, Singapore*  
This robotics competition encourages students to develop problem solving skills, entrepreneurial skills, creative thinking skills, and team spirit among the participants.  
[www.science.edu.sg/events/pages/njrcompetition.aspx](http://www.science.edu.sg/events/pages/njrcompetition.aspx)
- 15** **Robotour**  
*Czech Republic*  
Autonomous navigation in a park carrying a five liter barrel of beer.  
[www.robotika.cz](http://www.robotika.cz)
- 21-23** **RoboCup Junior Australia**  
*Canberra, Australia*  
RoboCup Junior Australia is a project-oriented

educational initiative that supports local, regional, and international robotic events for young students. Teams work in a co-operative and supportive environment in three distinct challenges: Dance, Rescue, and Soccer.  
[www.robocupjunior.org.au](http://www.robocupjunior.org.au)

## OCTOBER

- 1-4** **UAV Outback Challenge**  
*Kingaroy, Australia*  
Search and Rescue Challenge, Airborne Delivery Challenge, and Autonomous.  
[www.uavoutbackchallenge.com.au](http://www.uavoutbackchallenge.com.au)
- 19-21** **Critter Crunch**  
*Hyatt Regency Tech Center, Denver, CO*  
Robot combat — 2 lb and 20 lb event categories. Autonomous and remote control. Starting size of 12" x 12" x 12". Weight limit of 20 lb. Power source must meet OSHA requirements for indoor use.  
[www.milehicon.org/?page\\_id=16](http://www.milehicon.org/?page_id=16)

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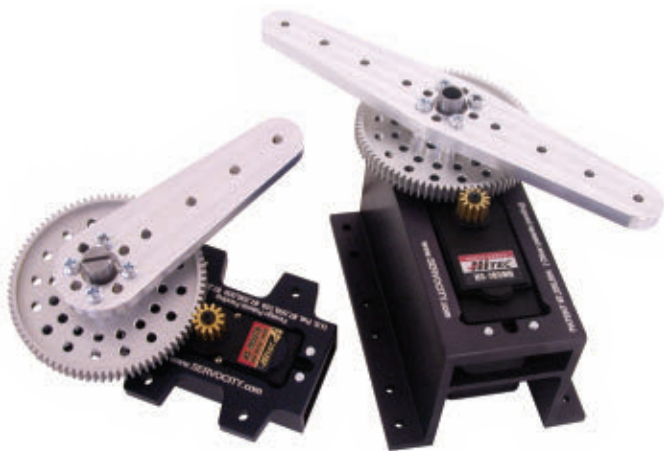
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# NEW PRODUCTS

## Enhanced Digital Servo Gearboxes



**S**ervoCity has revamped their line of servo power gearboxes. All of the servo power gearboxes that use an external potentiometer are now digital rather than analog. Digital servos provide more torque, higher precision, faster response times, and are fully programmable. The programmable features allow the user to tailor the servo to perfectly fit various applications. To handle the additional torque, new 32 pitch gears now drive the output shaft. The new hub/spur gears are constructed of 7075-T6 aluminum; the servo gears are constructed of hardened brass gear-stock and broached to ensure a perfect fit on the output spline of the servo. Metal gears now come standard on all of the servo power gearboxes. The new .770" hub pattern with 6-32 threaded holes has replaced the former .625" pattern to more solidly attach components. In addition to these changes, the external potentiometer has been refined and is now protected by a sleek aluminum cover. The new potentiometers are much smaller than the previous models, yet offer more precise positioning feedback.

The updated servo power gearboxes can be purchased in kit form or as fully assembled units that are ready for use.

## Digital Manual Speed Controller



**S**ervoCity is also offering a simple and affordable way to precisely control gearmotors and linear actuators. The

digital manual speed controller provides proportional forward and reverse control from the 5K potentiometer input. This controller is nearly bullet-proof since it is protected from reverse voltage, over-voltage, over-temperature, and over-current. The advanced technology implemented into the digital manual speed controller offers extremely fine low speed and bi-directional control, while maximizing the available torque. The controller accepts 4.8-24 VDC and can handle a maximum of 10 amps continuous. It has a small footprint of just 2.4" x 2.4" and weighs in at only four ounces. The new digital manual speed controller is perfect for pan and tilts, time-lapse rigs, camera sliders, or any application which requires fluid, bi-directional control of a DC motor.

For further information, please contact:

**ServoCity**

Website: [www.servocity.com](http://www.servocity.com)

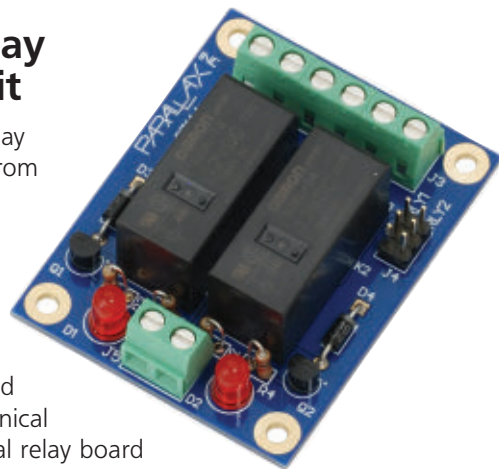
## Dual Relay Board Kit

**T**he Dual Relay Board Kit from Parallax allows you to control two high power devices up to 8A each via the included

Omron mechanical relays. The dual relay board can be used to turn lights, fans, and motors on/off while keeping them isolated from the microcontroller. Independent control of each relay is provided via a 2 x 3 header, making it friendly with servo cables and providing a convenient connection to many development boards such as the Board of Education, Propeller Board of Education, Professional Development Board, and Propeller Professional Development Board. LEDs indicate relay status.

Features include:

- Comes as a kit providing lower cost.
- Control two high power devices with one kit.
- Provides isolation between microcontroller and device being controlled.
- Easy screw terminals for relay contact and power connections.



- Three-pin servo-style headers for easy connection using standard servo cables.
- LED indicators provide status of each relay.

Price is \$19.99.

## Stampduino

**P**arallax is also now offering a BASIC Stamp development board designed to be compatible with most Arduino shields reducing space and size requirements, with the purpose of optimizing the user's systems.

Features include:

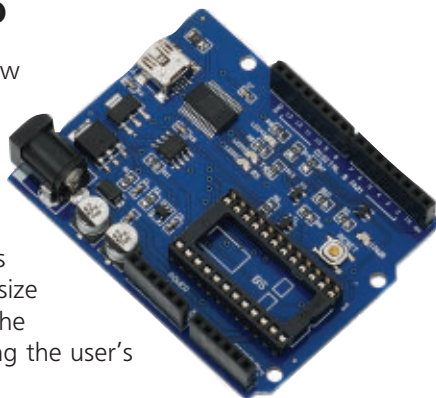
- All 16 digital I/O pins are free to use, allowing full utilization of the capabilities of the BASIC Stamp.
- Compatible with most Arduino shields, for ease of use between systems.
- Integrated Serial Communication LEDs for a visual confirmation of data transfer.
- Surface-mounted 3.3V regulator to accommodate the incorporation of 3.3V devices into applications.
- USB or externally powered, for rapid prototyping.

Price is \$29.99.

For further information, please contact:

**Parallax**

Website: [www.parallax.com](http://www.parallax.com)



## Digital Golf Glove

**S**ensosolutions has a new version of SensoGlove which offers a longer battery life and increased sensitivity for a more accurate pressure read to help ensure a consistently smooth and powerful golf swing for greater distance and lower scores. The new version of SensoGlove was created based on feedback from international PGA professionals.



SensoGlove features a small, sweat-proof 1.2 inch LED digital monitor that analyzes the pressure of the swing through highly responsive sensors placed throughout the glove. Swing the golf club to receive real time audio and visual feedback at 80 times per second by the small sensors that warn if you exceed your target level of grip pressure. The patented SensoGlove also shows which fingers are gripping too tightly, so you can adjust your grip accordingly.

Made of high quality cabretta leather, SensoGlove is available for men and women in right or left hand configurations, in sizes small to extra large. The built-in digital monitor can be removed to use SensoGlove as a regular golf glove.

For further information, please contact:

**SensoGlove**

Website: [www.sensoglove.com](http://www.sensoglove.com)

## USB Mini Connector Board

**S**chmartBoard has expanded its product line with a prototyping board for an inexpensive, quick, and easy addition of a through-hole USB Mini B connector to a prototype or electronics project.

The board has two through-hole USB Mini B connector 0.5" x 2" grids. Four ground holes are connected to a copper plane on the bottom side. The new board is a member of a family of specialized through-hole boards which support parts such as USB, RJ11 and 45, switches, RS-232, ATX power, DB 25, JTAG, RGB, and more.

The suggested retail is \$2.50 each or \$20 for a ten pack.

For further information, please contact:

**SchmartBoard**

Website: [www.schmartboard.com](http://www.schmartboard.com)



Is your product innovative, less expensive, more functional, or just plain cool? If you have a new product that you would like us to run in our *New Products* section, please email a short description (300-500 words) and a photo of your product to:

**[newproducts@servomagazine.com](mailto:newproducts@servomagazine.com)**

# bots IN BRIEF



## WHAT'S IN THE TRUNK?

“Jamming” has to be one of the coolest new actuation techniques we’ve seen in the last couple years. However, MIT may have just topped everyone by developing a robotic elephant trunk that’s strong, flexible, and — since it’s made mostly out of coffee grounds — absolutely dirt cheap.

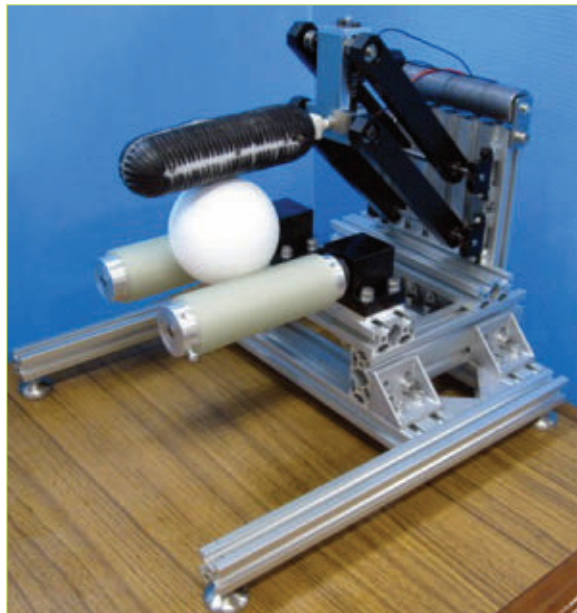
The jamming technique was developed jointly at Cornell University, the University of Chicago, and iRobot back in late 2010. Basically, you take a balloon and fill it with coffee grounds, so you have a squishy blob. Then, you pump all of the air out of the balloon so the coffee grounds “jam” together into a solid mass. Your squishy blob all of a sudden turns rigid, firmly gripping anything it had blobbed around. The key point is

this: By adding or removing air, a jamming system can go from flexible to rigid and back again.

A group of researchers from MIT took this concept and applied it to a robotic arm that looks just like an elephant’s trunk and has similar movement capabilities, as well. The arm is made up of a bunch of different jamming segments stuck together at the ends, with separate vacuum valves to each segment and a set of four control cables spaced at 90 degree intervals around the outside of the entire thing. As the control cables pull on the arm, the segments smoothly flex, but by jamming selected segments and turning them rigid (an operation that takes just 0.2 seconds), you can alter the motion of the arm in complex ways, allowing trunk-like gripping motions.

What’s great about this gripping system (besides the look, of course) is that it’s very cheap and very robust, while being simultaneously as rigid and as flexible as you like. You can add lots more segments without increasing the overall complexity of the system, as well. The “cheap” part will likely be the most appealing to researchers and hobbyists since all you need to make this thing (more or less) are thin flexible membranes (like balloons), cables, drive motors, a vacuum source and tubing, and (most importantly) some coarse-ground coffee. Yes. They checked. Coarse ground is more effective than fine ground.

Next up for the trunkbot is a bunch of tweaking to try to find the ideal filler material (both grain size and composition being important), followed by the addition of some sort of manipulator which really should be something like this just to keep the intermittently squishy theme going. Next comes embedded sensing, control, path planning, and all that kind of stuff, followed by a potential career in underwater robotics where the external pressure exerted by the sea water makes the jamming pressure far higher than you’d find on land.



## FINGERED FOR THE FUTURE

One of the things we love about robots is that they can be designed to do things that humans can’t. It’s not just that they can do some things better; it’s that they can take a piece of ourselves (like fingers) and improve on them to enable totally new capabilities. Osaka University’s Omni-Finger is just such a robot, giving artificial fingers an entirely new dimension.

Omni-Finger will include three digits to enable robots to arbitrarily alter the orientation of objects that they’ve grasped without having to set the object down, manipulate it, and re-grasp it, making grasping tasks as a whole easier and much more efficient. The only problem remaining is to figure out how to keep the fingers in contact with an irregular object as the fingers move it around, but the researchers are working on some creative ideas involving surrounding the fingers with deformable sacks filled with some sort of viscous fluid.

Imagine for a second what could happen in the future when robots start playing baseball with hands like these. Talk about a curveball!

# bots IN BRIEF

## PUTTING A WRINKLE IN THINGS

Remember CLASH, the first purpose-built cloth climbing robot ever constructed? Clearly, just having one robot that can conquer clothing is not nearly enough, so a team of roboticists from the Chinese Academy of Sciences has decided that we need a little robot specifically designed to climb up wrinkles. Unlike CLASH — which climbs with little spiny legs — Clothbot uses a gripping mechanism that can create a wrinkle in a piece of cloth with a pair of opposed gripper wheels and then drive straight up it. Clothbot only weighs about 140 grams, and it also includes an omni-directional tail that adjusts the bot's center of gravity and helps it to change direction. The upside over a robot like CLASH is that Clothbot doesn't leave little claw-holes all over your stuff, but instead just a slight fold that merely makes you appear unkempt.



So, what exactly does Clothbot do when it gets to the top of your pants or your jacket or your shirt (or whatever)? We have no idea, but it's been suggested that it could be used as "a tiny pet climbing on human bodies" or even "a movable phone on your shoulder which frees human hands." One other intriguing possibility from the creators is "body inspection." Yeah. We'll let you use your imagination on that one.

## DOG GONE FUN

Go-Go Dog Pals has introduced one of the few remote control toys for dogs on the market, which they feel can revolutionize your dog's exercise and lifestyle. These



sustainable toys will give your dog a fun, stimulating, and challenging workout while giving you a chance to save both time and energy. Each of these remote control pet toys is outfitted with an advanced system that allows for long range operation, allowing you to take a break while your dog exercises. The remote control system is powerful and easy to navigate, so kids, seniors, and everyone in between can get in on the fun. Each Go-Go Dog Pal can travel at a high speed, providing your dog with an exciting chase outside.

Go-Go Dog Pals are built from a durable, lightweight material and are designed for action. Combined with this remote control system is a sturdy chassis. Components in the chassis are rechargeable and/or replaceable. When a Frisbee or real gopher just won't do, get a Go-Go Dog Pal. The Solana Beach, CA based company will send you one for about \$299.99.



## (NOT) IN THE DUMPS

How would you like to have a robot that would decompose once it finishes its task? Well, the University of Bristol, UK is working on a research grant to do just that.

Ecobot will be made of plant textiles and bioplastics that can be digested by organisms. Dr. Jonathan Rossiter, head of the team, claims that, "Once a biodegradable robot has reached the end of its mission, for example, having performed some environmental cleanup activity following an oil spill, it will decompose into harmless material."

We could see these environmentally friendly robots hanging out in disaster areas or getting a one-way ticket to a planet far, far away.

Conventional robots are predominantly made of rigid resilient materials, many of which are toxic, non-biodegradable, and have a negative impact on the natural ecology. Any robot deployed in the environment must therefore be continually tracked and — once it has reached the end of its useable life — must be recovered,

dismantled, and made safe. This adds enormous complexity to the running of robotic projects and there is the ever-present risk that the robot will be irrecoverable with consequent damage to the eco-system. Additionally, these characteristics severely limit the number of robots that can be employed since each must be tracked and recovered.

## IN THE BUBBLE

We're used to thinking of robots as mechanical entities, sometimes at very small scales. Sometimes it becomes easier to simply use existing structures like micro-organisms that respond to magnetic fields or even swarms of bacteria instead of trying to design and construct one (or lots) of these teeny tiny artificial machines. Aaron Ohta's lab at the University of Hawaii at Manoa has come up with a novel new way of creating non-mechanical microbots — quite literally out of thin air — using robots made of bubbles with engines made of lasers.

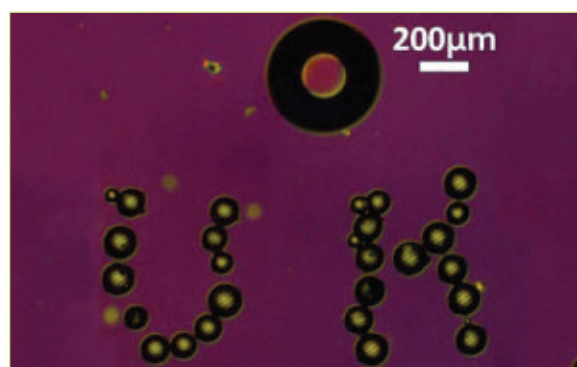
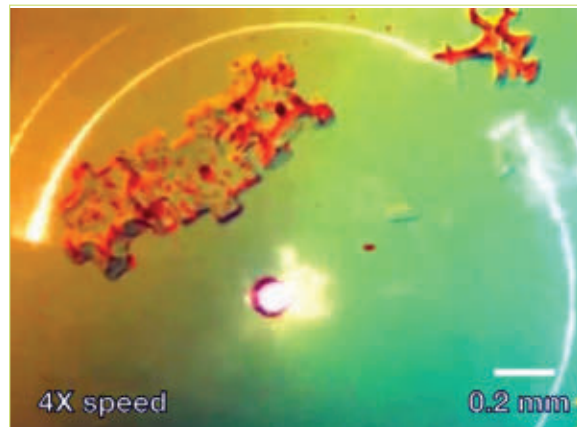
To get the bubble robots to move around in this saline solution, a 400 mV 980 nm (that's infrared) laser is shone through the bubble on to the heat-absorbing surface of the working area. The fluid that the bubbles are in tries to move from the hot area where the laser is pointing towards the colder side of the bubble; this fluid flow pushes the bubble towards the hot area. Moving the laser to different sides of the bubble gives you complete 360 degree steering, and since the velocity of the bubble is proportional to the intensity of the laser, you can go as slow as you want or as fast as about 4 mm/s.

This level of control allows for very fine manipulation of small objects. The picture here shows how a bubble robot pushed glass beads around to form the letters "UH" (for University of Hawaii, of course).

Besides being able to create as many robots as you want of differing sizes out of absolutely nothing (robot construction involves a fine-tipped syringe full of air), the laser-controlled bubbles have another big advantage over more common microbots in that it's possible to control many different bubbles independently using separate lasers or light patterns from a digital projector. With magnetically-steered microbots, they all like to go wherever the magnetic field points them as one big herd, but the bubbles don't have that problem since each one just needs its own independent spot of light to follow.

The researchers are currently investigating how to use teams of tiny bubbles to cooperatively transport and assemble microbeads into complex shapes, and they hope to eventually develop a system that can provide real time autonomous control based on visual feedback.

Eventually, it may be possible to conjure swarms of microscopic bubble robots out of nothing, set them to work building microstructures with an array of thermal lasers, and then when they're finished, give each one a little pop to wipe it completely out of existence without any mess or fuss.





NASA JPL's Lemur IIB robot hanging from a microspine anchor. (Image courtesy of NASA/JPL.)

## IT'S THE CLIMB

We're no strangers to innovative climbing robot research but we don't often get to see what happens when some of this technology makes the leap from laboratory curiosity to potential application. Aaron Parness from Stanford has brought Spinybot's legacy to NASA's Jet Propulsion Laboratory, where they're working on a microspine adhesion system for sticking robot probes to asteroids.

Back in 2007, the European Space Agency launched the spacecraft Rosetta on a mission to a comet that will arrive in 2014. Rosetta includes a lander that will use a harpoon to stick itself to the surface of the comet which (while pretty cool) isn't necessarily an ideal solution since harpoons aren't removable. Ideally, you want some system that can reliably anchor a robot to an uneven surface while simultaneously providing enough downforce in microgravity to allow for sample collection. This is where the microspines come in.

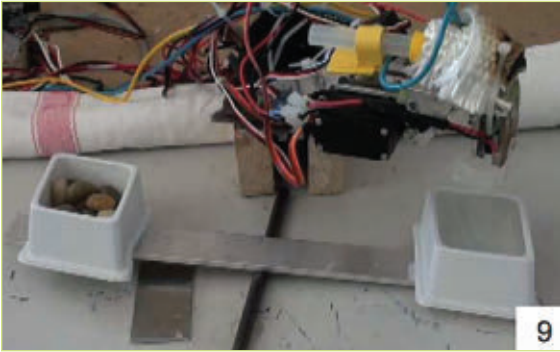
JPL's microspine anchors are capable of quickly attaching and detaching from a variety of surface types using an actuator with just one degree of freedom. The anchor provides enough force (on surfaces ranging from vertical to inverted) for a percussion drill operating through the anchor to take core samples, and it's robust enough to survive over a hundred anchoring sequences with a structure that's designed to be space-durable.

Next, JPL will be refining an ankle and foot equipped with this same spine system; the goal being to get one of their limbed robots (Lemur IIB) to be able to climb around vertical and inverted rocky surfaces. This would potentially be ideal for the exploration of asteroids and comets, or for crawling around the walls and ceilings of lava tubes on, say, Mars to collect mineral samples. There's also talk of somehow applying this system to astronauts, probably for microgravity anchoring.

## MAID FOR DANCING

Dr. GIY (a prominent member of the Japanese ROBO-ONE community) has designed and built a new custom robot. At 52 cm (20.4 inches) tall, Pre-maid Me won't be doing the housework any time soon, but with a total of 27 degrees of freedom she's capable of some pretty fancy footwork! As is typical of most Japanese do-it-yourself robots, this one was built and programmed using Kondo servos and software. It's available in kit form as the Kondo KHR-3HV.





## STICKY BUSINESS

Humans are generalists. We're adaptable. If there's a task we can't do on our own, we find ourselves a tool to help us. Robots aren't usually like this, because it's very hard to design a robot that implements all the different tools that might conceivably be useful to it. However, roboticists at ETH Zurich are trying to get around this problem by designing a robot with just one tool: a hot glue gun that their robot can use to manufacture any tools it needs.

ETH has some experience with robots and hot glue (which they call Hot Melt Adhesive, or HMA). One of their previous robot builds uses HMA to climb up walls, but HMA can be used

as much more than just an adhesive. By building up layers of HMA material, you can construct simple shapes. ETH has designed a robot that uses this technique to create a tool from scratch that enables it to complete a task that it wouldn't otherwise be capable of doing. Say for example, the robot needs a way to transport water from one location to another.

First, the robot uses HMA to construct the base and sides of a cup, one layer at a time. This takes about half an hour to complete. The construction surface is aluminum, covered in a thin layer of oil to keep the HMA from sticking too much. While the cup cools (and solidifies), the robot builds a small bar out of HMA nearby and allows it to cool. When the bar has cooled sufficiently, the robot places a heating element against the bar, melting the bar onto itself. The heating element is turned off, and when the bar has cooled, the robot pulls it off of the construction surface. The robot adds a little dollop of HMA to the side of the cup, and then sticks the other end of the bar onto the cup and lets the HMA bond to itself. Finally, the robot pulls the bar and the attached cup off of the construction surface and gets to work.

You've probably noticed the similarities between this process and 3D printing, which is much faster and provides a lot more detail. The reason this robot can't just 3D-print a cup is that the thermoplastic materials don't provide any good ways of bonding objects to the robot itself which would mean that the robot would have complex manipulators and have to deal with grasping. The whole point (or part of the point) of the HMA is to make complicated things like that unnecessary.

While the actual execution of a task is performed autonomously by the robot, the planning was not since the robot doesn't yet have a perception process. This is something that the researchers will be working on in the future, and they fantasize about a robot that can adaptively extend its body how and when it deems fit. They also suggest that this technique could be used to create robots that can autonomously repair themselves, autonomously increase their own size and functionality, and even autonomously construct other robots out of movable HMA parts and integrated motors — all of which sounds like a surefire recipe for disaster.



## WALKING TALL

Clair Lomas walked approx. two miles a day of the 26.2-mile route of the London Marathon, cheered on by husband Dan, mother Joyce, and 13-month-old daughter Maisie.

That may not sound like much of a feat, but the 32-year-old (from Eye Kettleby, near Melton Mowbray, Leicestershire) was left paralysed from the chest down following a horse riding accident in 2007.

Despite this, she set off on April 22 with 36,000 people participating in the marathon. As she crossed the finish line, she became the first person to complete any marathon using a bionic ReWalk suit.

A number of celebrities lent their support by walking a mile alongside her, including local TV presenters, and a former international rugby star.

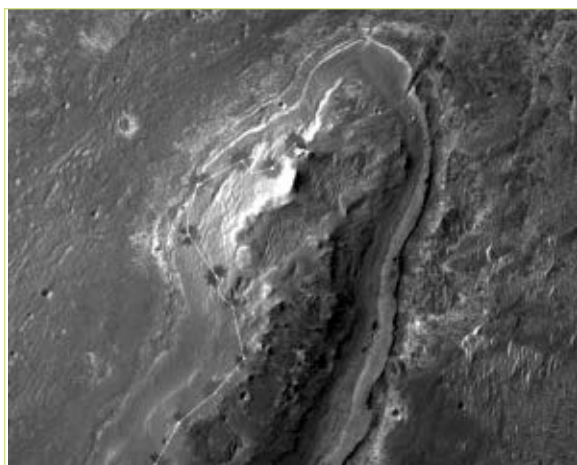
Lomas did not appear in the official results or qualify to receive a medal when she finished because competitors have to complete the course on the same day to qualify.

The mother-of-one broke her neck, back, and ribs, and punctured a lung when her horse Rolled Oats threw her off as she took part in the Osberton Horse Trials in Nottinghamshire.

## OPPORTUNITY CONTINUES

The photo on the right shows the spot that the Mars rover, Opportunity, has been sitting on for the last several weeks doing its level best to try not to starve to death from lack of solar power. Opportunity has been stuck on a little outcropping (called Greeley Haven) to keep her solar panels oriented more directly at the sun. Finally, now, the sun is high enough in the sky for Oppy to get her roll on, and she snapped this pic looking backwards after a three meter drive into unexplored terrain.

It's a shame that Opportunity doesn't make the news more often for the mere fact that she's still wandering around on Mars and doing science. The robot landed in 2004, and the original mission was slated to last 90 days, but she's gone beyond that by almost 3,000 days. Besides dust collecting on the rover's solar panels, the only issue Opportunity has really had is a misbehaving shoulder joint which necessitates driving with her arm deployed. (Not bad for a total distance driven of nearly 35 kilometers.)



*An orbital view of Opportunity's current location on Mars;*

In the short term, Oppy will make sure that she's getting enough solar power to keep driving and doing science. Her winter spot on the outcropping kept her tilted 15 degrees northward towards the sun, and after this drive, she's only tilted eight degrees. If everything looks good, the rover will travel another few meters towards a bright looking patch of dust to investigate.

Of course, we don't want to forget NASA's new, bigger, and more capable rover, Curiosity, currently en route in space and scheduled to land on Mars in August. It's going to be tough for the new rover to live up to the expectations set by its predecessors.

The \$69,000 ReWalk suit she used for the marathon — designed by Israeli entrepreneur Amit Goffer — is meant for people with lower-limb paralysis to help them stand, walk, and climb stairs through motion sensors and an onboard computer system.

A shift in the wearer's balance — indicating their desire to take, for example, a step forward — triggers the suit to mimic the response that the joints would have if they were not paralyzed.

The amazing Lomas finished the London Marathon in 16 days.

She did receive a special cup for her participation.

The courageous marathoner has raised over \$128,000 for Spinal Research — an organization that funds research and treatments for back and neck paralysis. Although she says she is just glad to have earned the money for the organization, a campaign is underway to see that she is properly awarded for her performance. Several other runners donated their medals to her.



*Claire Lomas taking part in the London Marathon.  
(Image courtesy of Geoff Pugh.)*

# COMBAT ZONE

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## BUILD REPORT:

### *Horses for Courses*

● by Pete Smith

Combat robotics is — in many ways — a game of Rock-Paper-Scissors. If everything else is equal, a brick will beat a spinner; a flipper will beat a brick; and a spinner will beat a flipper.

However, life is more complex than a game and there are many varieties of bots. To increase your chance of winning a fight, it's a good idea to be able to modify your bot to take advantage of your opponent's weaknesses or to neutralize its strengths.

My Beetleweight Trilobite allows for the attachment of different devices; you can design these so you can match up better with opponents. In preparation for Motorama, I developed some new attachments to counter those bots that I thought were the toughest competitors.

First, there are the

wedges and flippers. These need to get under your bot to be effective. To beat them, you stop that and, in turn, get under them so you can push them around, overturn them, or slam them against the wall.

The top Beetleweight flipper at the moment is The Revenge of Doctor Superbrain (**Figure 1**). I designed a low angle, pivoted wedge (**Figure 2**) that works even if the bot is inverted. The shallow angle

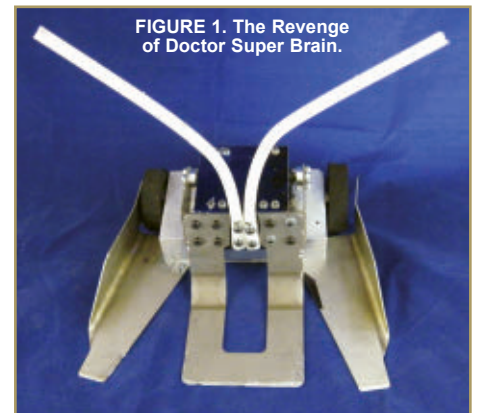


FIGURE 1. The Revenge of Doctor Super Brain.

and sharpened front edge mean that it will have a good chance of success over most wedges and flippers if driven well.

Traumatizer (Figure 3) is an effective horizontal bar spinner and the best defense is a simple solid wall. As the spinner hits the wall, it can do little damage. However, Newton's 3rd Law applies the same forces to the spinner and with luck, the spinner will break before your bot does. I attached a 1/2" thick block of UHMW (backed by a foam block to further absorb the hits) to the same standard mounts on Trilobite (Figure 4).

Weta — God of Ugly Things (Figure 5) — is a fairly typical drum spinner. These designs work by biting into the opponent and using the kinetic energy stored in the rotating drum to rip parts off or throw the opponent up into the air. To defeat them, I attach a narrow and very solid UHMW wedge to a thick titanium plate (Figure 6). This works by getting under the drum so that when the teeth contact the wedge or the plate, it's the drum bot that gets thrown not Trilobite. With the weapon on the drum bot neutralized, it becomes a pushy fight and the advantages shift to Trilobite with its more powerful drivetrain.

Mr. Croup (Figure 7) has been one of our main rivals in recent years. Its powerful vertical beater is combined with a ground-hugging

FIGURE 2. Attachment for The Revenge of Doctor Superbrain.



FIGURE 4. Attachment for Traumatizer.



FIGURE 6. Attachment for Weta.

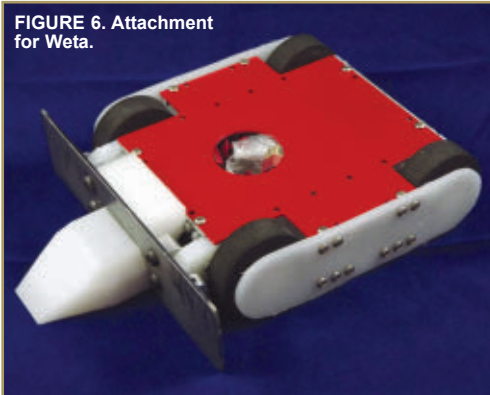


FIGURE 3. Traumatizer.



FIGURE 5. Weta.

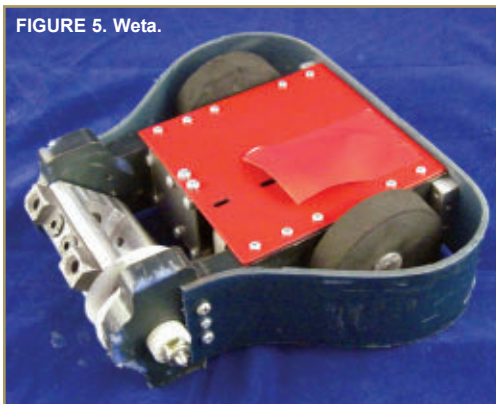
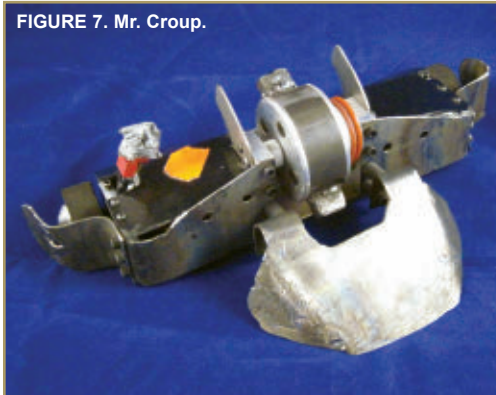


FIGURE 7. Mr. Croup.



wedge. It is, however, very wide with large vertical panels on either side of the wedge. I made a large U shape out of 1/4" UHMW and faced the center section with a thick titanium panel (Figure 8).

It is intended that the extremities of the U shape will contact the vertical panels on either side of the wedge and allow Trilobite to push Mr. Croup while simultaneously keeping the wedge and the beater bar from making contact. This neutralizes their weapon and again shifts the

advantage to Trilobite.

At Motorama, only two of the options were used. The wedge proved useful in beating Ripto and the anti drum attachment was used in a fight against Weta (a loss due more to luck than skill on my part, as I was driving Weta and my son, Andrew, was driving Trilobite). Mr. Croup was not at its best and was knocked out early by Weta; we were never drawn against a horizontal spinner like Traumatizer.

I will design at least one more

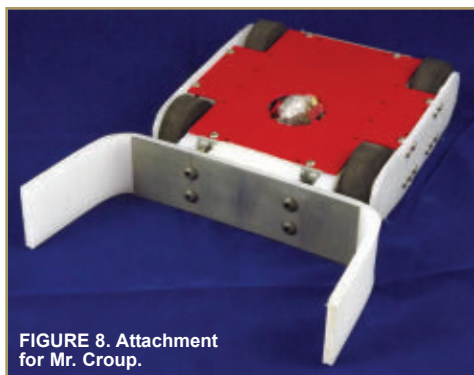


FIGURE 8. Attachment for Mr. Croup.



FIGURE 9. Damage from Ripto.

attachment. A large dustpan type scoop would have been useful to

help control an RC toy based bot, Chobham, which defeated Trilobite

be ready for when you meet them in the arena. **SV**

in a judge's decision. I will also replace the 7075 aluminum in the plain wedge with titanium, since it suffered a lot of damage (Figure 9) in its fights against Ripto.

It's not enough to just focus on making your bot. You need to also look at your possible opponents and

# BUILD REPORT:

## Siafu: an Army of Ants – Part 2

● by Pete Smith

In Part 1 of this series, I outlined the design process I went through to establish the basic layout of my new drum Ant kit. In Part 2, I will detail the design of the drive motor mounts, the hubs and wheels, the drum and its mountings, and the design of the front wedge profile.

The new motors are similar to the larger ones used in my Weta and Trilobite Beetleweight kits. They have a cylindrical gearbox and a motor no larger in diameter than the gearbox. There are two M2 tapped holes in the front of the gearbox — again similar to the larger motors.

I designed a flat plate that could be mounted onto the front of the motor (Figure 1). The first plates I made were 0.030" thick aluminum but while these worked, I found that 2 mm long screws were a little too short and 3 mm ones were a little too long and interfered with the mechanism inside the gearbox. A thicker 0.060" plate allows the 3 mm screws to secure the plate without damaging the internal gears. Four holes sized for #2 screws provide a method to secure the gearbox to its place in the chassis.

In the past, I have used Dave's hubs and Lite Flite wheels (Figure 2)

in my small bots. These have worked well. They are light and resistant to damage, but I have found that the Loctite® required to secure the outside washer can make it hard to remove, plus access to the motor mounting screws is difficult without removing it. This can be a problem in a competition if a wheel or motor is damaged and needs to be replaced. A different Loctite may help, but I decided to try out another design of the wheel and hub in the Ant.

Banebots ([www.banebots.com](http://www.banebots.com)) offers an alternative hub and wheel. The hub is hexagonal (Figure 3) and is held to the motor

FIGURE 1. Ant motor plus mounting plate.

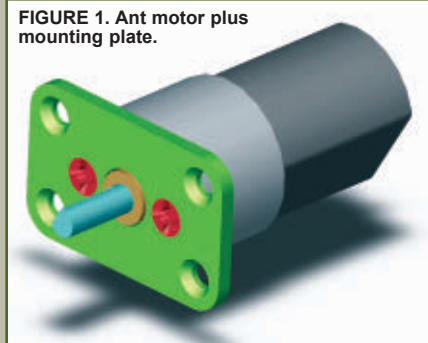


FIGURE 2. Dave's hub.

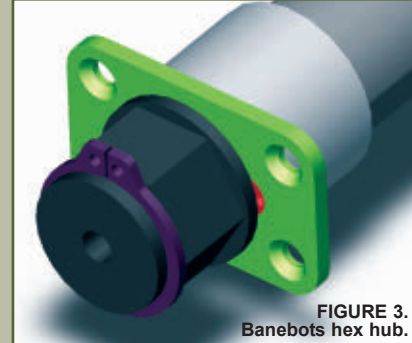
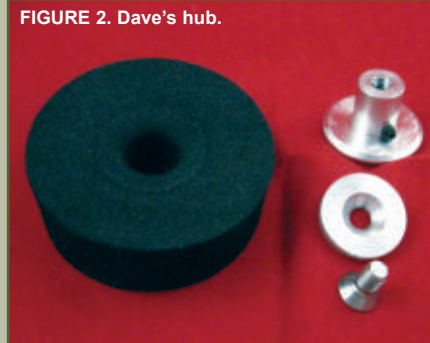


FIGURE 3. Banebots hex hub.

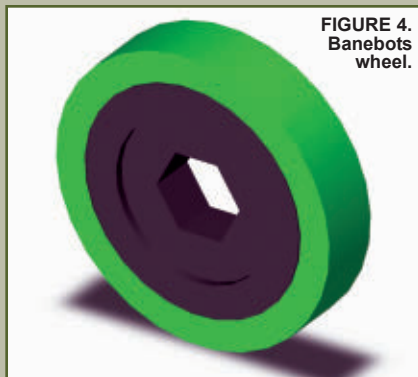


FIGURE 4. Banebots wheel.



FIGURE 5. Turnigy 28 mm outrunner.

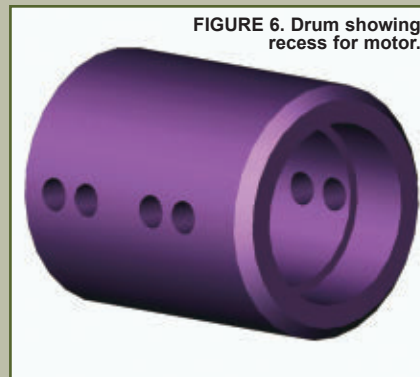


FIGURE 6. Drum showing recess for motor.

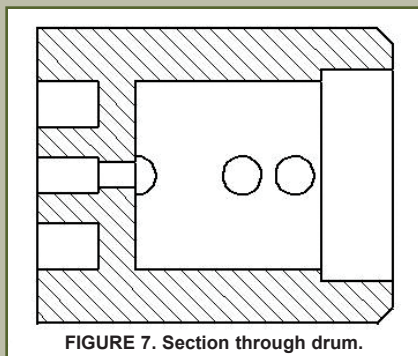


FIGURE 7. Section through drum.

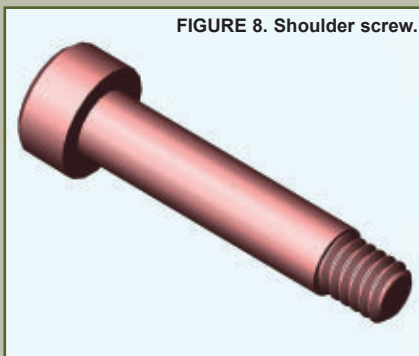


FIGURE 8. Shoulder screw.

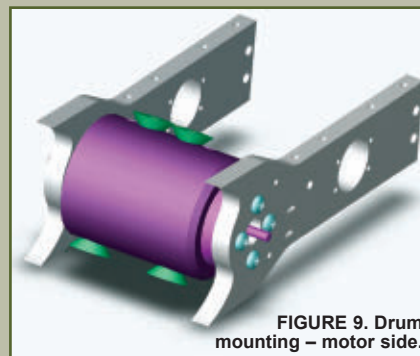


FIGURE 9. Drum mounting – motor side.

shaft with a set screw just as on a Dave's hub. However, the wheel (**Figure 4**) — which has a matching hex — is held with an external retaining clip (circlip) rather than by a washer and screw. By using the Banebots wheel in my design, replacing a failed wheel or drive motor is made simpler since the clip is quickly removed and access is made easier. The design of the bot will also allow the use of the Dave's hubs, so the design is not dependent on a single source.

The weapon motor I plan to use (**Figure 5**) is a Turnigy Aerodrive SK3-2822-1740kv outrunner from [www.hobbyking.com](http://www.hobbyking.com). The drum will rotate around the motor at one end and on an axle running on a flanged bearing at the other. The drum design (**Figures 6 and 7**) has a recess the diameter of the motor bell at one end, and a bore and thread at the other that is designed to locate and secure a shoulder screw (**Figure 8**). These screws have a hardened and ground shaft which makes an ideal axle.

The bell of the motor will be pressed and glued into one end of

the drum, then that end of the drum will be secured to the chassis using four M3 screws put into the motor's front face mounting holes (**Figure 9**). The other end will be secured with the shoulder screw running through a flanged bearing and a couple of nylon washers (**Figure 10**). The wires from the motor will run back along the chassis wall into the inside of the chassis.

The drum will be machined from 7075 aluminum. This grade of Al is very tough but still easy to machine. Two 1/4" flat head screws will be fitted on either side of the drum to act as teeth.

To help the bot deal with

wedges and brick bots, I want the chassis to bring other bots up into the spinning teeth on the drum. To do this, I have adopted a chassis profile similar to that used on Team Pneusances Beetleweight Grande Tambor ([www.buildersdb.com/botpics/8203.jpg](http://www.buildersdb.com/botpics/8203.jpg)). The profile (**Figure 11**) allows the chassis rails to act as wedges even if it is inverted. The points of the wedge are somewhat vulnerable to horizontal blade spinners, but I think for most other fights they will give the bot an advantage.

Part 3 of this series will cover the ordering of parts, and assembly and testing of the first rolling chassis. **SV**

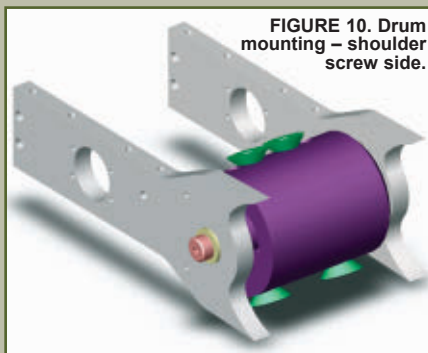


FIGURE 10. Drum mounting – shoulder screw side.

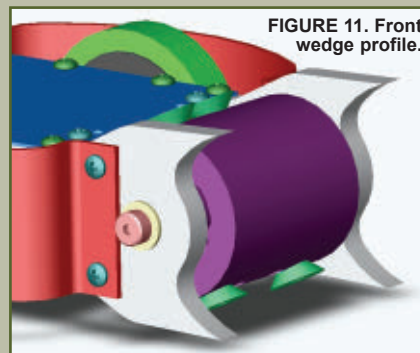


FIGURE 11. Front wedge profile.

# EVENT REPORT:

## Insects Invade RoboGames

● by Dave Graham



FIGURE 1. The Calkins family – Simone, David, and daughter Emma.

An international swarm of over 130 Insect class robots invaded the fairgrounds in San Mateo, CA to compete in fighting robot events at RoboGames 2012. This year's Insect robot combat events included 150 gram Fleas (a.k.a., Fairy), one pound Ants, three pound Beetles, and one and three pound autonomous bots. RoboGames 2012 offered 59 events that drew 682 robots built by 238 teams from 16 countries. Nine of the 59 events were combat robot events and six of those nine events were for the Insect class bots. That means approximately one-fifth of the robots competing at RoboGames and two-thirds of the combat robot events were in the Insect class. Those are awesome numbers and truly represent the



FIGURE 2. Dave Wiley mentoring a first-time competitor.

competitive, international aura of RoboGames, and the importance of the Insect class fighting robots to the event. I just can't say enough good things about RoboGames. It is simply the best robotic event in the world and lives up to every bit of its pre-event hype. I need to acknowledge event organizers David Calkins and his wife Simone with daughter Emma (Figure 1) for putting together another amazing event. Simone's referee shirt is not a fashion statement — she controlled all combat fights in the big arena.

This year's swarm of fighting Insect robots was the largest group ever assembled for RoboGames. Dave Wiley was in charge of all the Insect class combat events. Dave brought many years of combat



FIGURE 3. Brazilian college student Marcella de Amorim Gue with her Fleaweight bot Pocket.

robotics experience to RoboGames from his work with the California Insect Bots and as the creator of Dave's hubs. I knew Dave was serious when he checked the weight of all bots with a balance scale. Dave was at his best mentoring first-time competitors (Figure 2 — note the balance scale) and ensuring veteran competitors didn't become complacent. Because of the large number of entries, two arenas were used for Insect matches. Fleas and Ants fought in an enclosed arena

FIGURE 4. Brazilian Fleaweight bot Pico Touro.



FIGURE 5. Brazilian blue shirt team from the University of Rio de Janeiro.



FIGURE 6. Australian draftsman Daniel Wiseman and his Fleaweight bot Vendetta Junior (right).





FIGURE 7. Troy Mock and his Fleaweight bot Tiny Terror.



FIGURE 8. Taft College STEM program Junior League competitors.



FIGURE 9. Junior League Antweight bot War pig.

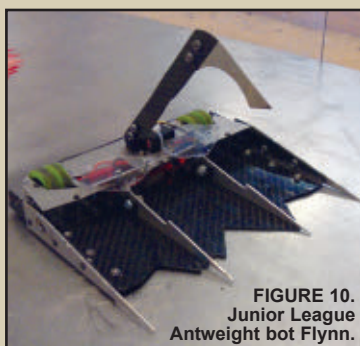


FIGURE 10. Junior League Antweight bot Flynn.



FIGURE 11. Antweight bot Kyle's Cutter (right) dislodges Antweight bot Robert's spinning drum.

with a four by six foot insert that had two push-out openings on opposite sides. The second arena was a hexagon shaped enclosed arena used for Beetleweights and all autonomous matches.

I tasted the international flavor of RoboGames right from the start when my Flea bot Hedgehog was paired against Brazilian college student Marcella de Amorim Gue from the University of Rio de Janeiro and her wedge bot Pocket (**Figure 3**). I lost the match, and Marcella went on to take third place with Pocket in the Flea competition.

The blue shirt Brazilian team is known for their Touro series of robots that all have one thing in common: a spinning drum. The smallest Touro bot is the 150 gram Pico Touro (**Figure 4**) and the largest is their 220 pound heavyweight monster Touro Maximus. I have to give a shout out to the Brazilian blue shirt team (**Figure 5**) as their patriotism and team spirit are simply over the top.

My second Flea match was against Australian draftsman Daniel

Wiseman and his bot Vendetta Junior (**Figure 6** — Vendetta Junior is on the right). I lost that match too and Vendetta Junior went on to a second place finish. Troy Mock of team Asian Invasion and his hacked Inertia Labs chassis wedge bot Tiny Terror (**Figure 7**) took the Flea gold. Remember the name Troy Mock — you'll see it several times in this article.

The Antweight competition was divided into three groups: Junior League for competitors under 18 years of age; Open for anyone 18 years of age and older; and Autonomous for all competitors regardless of age. There were several competitors under 18 years of age that had previously competed in the Open class at RoboGames, but this year the event organizers drew a hard line and did not allow junior competitors to move up to the Open class.

There were 38 bots registered for the Junior League competition. Two-thirds of those bots came from the Taft College STEM program. Taft College STEM program coordinator

Joe McFaddin explained the program is a partnership and includes school districts, educators, and corporate partners all working toward improving STEM subject interest and proficiency. Kudos to Joe for mentoring 58 middle schoolers enabling them to build 22 fighting robots and to compete in the Junior League Ant fighting robot event at RoboGames (**Figure 8**).

The Taft College STEM program students brought a diverse collection of fighting robots and gained valuable experience in the arena, but top honors in the Junior League were taken by three veteran competitors who all finished in the top three of the Junior League Ant competition at RoboGames 2010. Dawson Brown took third place with his bot Velociraptor, Troy Mock finished second with flipper bot War Pig (**Figure 9**), and Leif Hasle took the gold with Flynn (**Figure 10**). All three of these junior competitors could have fought in the Open Ant class and been competitive. Well done guys!

The Open Ant competition



FIGURE 12. Daniel Wiseman and Sarah Langlais with their Antweight bots Why You Mad Bro and Captain Crunch.

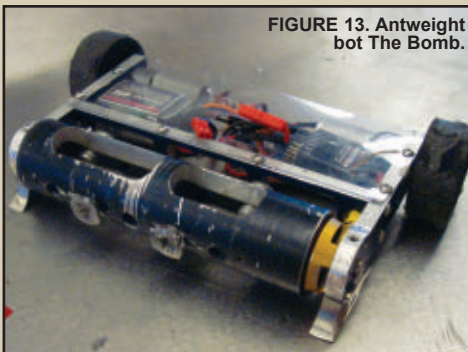


FIGURE 13. Antweight bot The Bomb.



FIGURE 14. Mexican Antweight autonomous bot Arrow One.



FIGURE 15. Damage to sensor wires on United Kingdom Antweight autonomous bot Wanderer.

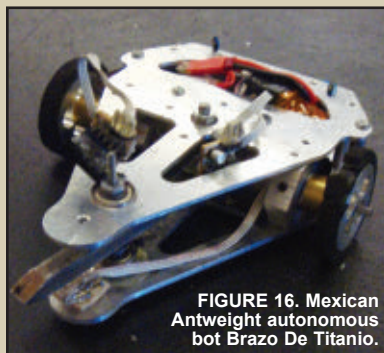


FIGURE 16. Mexican Antweight autonomous bot Brazo De Titanio.



FIGURE 17. Beetleweight bot Grande Tambor.



FIGURE 18. Beetleweight bot Attitude.

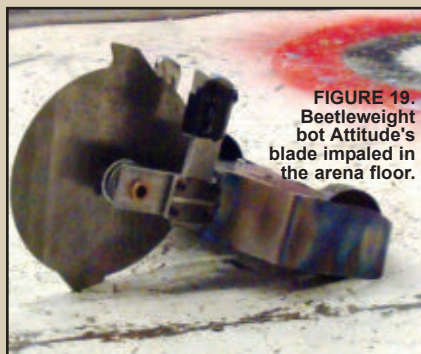


FIGURE 19. Beetleweight bot Attitude's blade impaled in the arena floor.

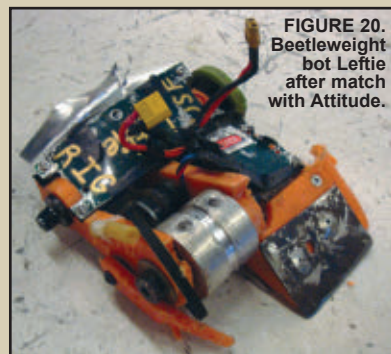


FIGURE 20. Beetleweight bot Leftie after match with Attitude.

drew the expected collection of destructive machines sporting all types of creative weapons. The spinners definitely took a chance this year putting big hits on their opponents at the risk of ejecting themselves through one of the arena openings. My first match with my horizontal spinner bot Kyle's Cutter was against a spinning drum bot from Mexico named Robort driven by college student Alejandro Vallejo. I won the match after dislodging Robort's spinning drum with a vicious hit (**Figure 11**).

Alejandro would repair the damage and Robort would return to fight in the Loser's bracket. Kyle's Cutter lost its next match to the University of South Florida's

Robotics Interest Group bot Capricant driven by Sam McAmis, and finished the day by launching itself out of the ring after a weapon-to-weapon collision with undercutter Peter the Anteater.

The Open Ant class also pitted a couple against one another when girlfriend Sarah Langlais and boyfriend Daniel Wiseman went head to head with their bots Captain Crunch and Why You Mad Bro (**Figure 12**). Sarah defeated her man in the first match on her way to a third place finish with her flipper bot Captain Crunch. Second place went to another flipper bot named Dust Pandemonium while spinning drum bot The Bomb (**Figure 13**) bullied the field on its

way to the Ant gold.

Both the Autonomous Ant and Autonomous Beetle competitions were conducted using a four foot by four foot insert in the hexagon arena. The insert had Plexiglas walls with push-out openings on opposite sides. The insert surface was black with the openings identified by a red line in front of them. The rest of the insert perimeter had a white line.

I always have high hopes for the autonomous bots and expect to see a methodical search and destroy strategy with both bots detecting and then closing in on their opponent with the weapon spinning for the kill. What's closer to the truth is competitors program their

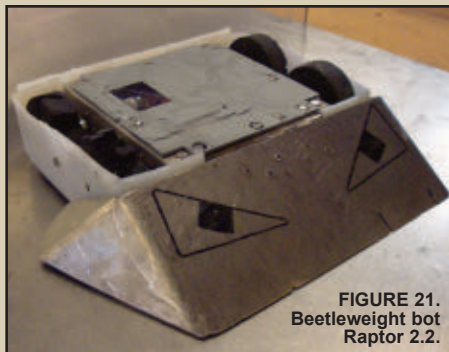


FIGURE 21.  
Beetleweight bot  
Raptor 2.2.



FIGURE 22. Father (Doug) and  
son (Dawson) of Team Dinobots.

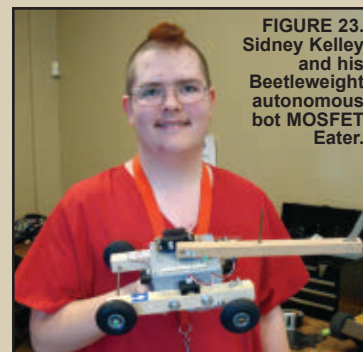


FIGURE 23.  
Sidney Kelley  
and his  
Beetleweight  
autonomous  
bot MOSFET  
Eater.



FIGURE 24. Beetleweight autonomous bot  
MOSFET Eater (right) attacking opponent.



FIGURE 25. John  
Frizell from the United  
Kingdom and his  
Beetleweight  
autonomous bot Otto.

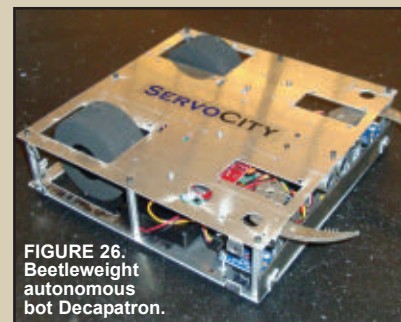


FIGURE 26.  
Beetleweight  
autonomous  
bot Decapatron.

bots to sense the edge line which causes their bot to change direction and aimlessly wander the arena in hopes of a chance collision with their opponent. At one point, a spectator described the autonomous competition as robots on valium. I found the moments of brilliance far outshined the slower portions of the autonomous competition. I learned a lot about autonomous robots and plan to compete next year.

The Autonomous Ant competition only had a handful of entries, but there were several exciting matches. Mexican bot Arrow One (Figure 14) finished in third place; second place finisher Wanderer from the United Kingdom had its front sensor wires cut (Figure 15) by the eventual first place spinner bot from Mexico, Brazo De Titanio (Figure 16). Brazo De Titanio actually cut Wanderer's front sensor wires twice — once in the quarter final match and again in the final match — causing Wanderer to drive into the wall and be counted out for non-movement.

The Beetleweight competition was absolutely brutal. Drum spinner Grande Tambor (Figure 17) finished in third place. Troy Mock and his big

vertical spinner bot Attitude (Figure 18) finished second and along the way impaled itself in the arena floor (Figure 19). Once pried free, Attitude went on to bludgeon South Florida University Robotic Interest Group bot Leftie (Figure 20) into submission. Beetle gold winner Dawson Brown's aggressive driving of his wedge bot Raptor 2.2 (Figure 21) in the championship match kept his opponent Attitude and its big spinner off balance and unable to land the big blows. Dawson competes with his father Doug (Figure 22) in the Beetleweight class as Team Dinobots with their appropriately named Beetle bots T-Rex 2.0 and Raptor 2.2.

Fourteen year old Dawson has been building and driving fighting robots since he was nine and also competes in two Junior League events: LEGO line following and Antweight combat where he took the bronze this year. This is his third year at RoboGames. Dawson recently completed his high school course work and now attends the local community college. Doug, Dawson, and mom Gena hail from Edmonds, WA and are active members of the Western Allied

Robotics group in Seattle.

The Beetle Autonomous competition also had flashes of brilliance. Eighteen year old competitor Sidney Kelley from Benson, AZ proudly shows his three pound autonomous creation MOSFET Eater (Figure 23). Sidney's design was unique in that he used a Pololu Maestro servo controller and a pair of Pololu 2.4 GHz wireless WIXEL modules. The onboard WIXEL module held the main bot code and used onboard scripting to read sensor data from the Maestro, and control the bot movement and weapon.

The WIXEL pair also provided the bot activation and fail-safe signals via a "keep alive" pulse instead of using a traditional RC transmitter/receiver pair. Pololu engineers in attendance were impressed by Sidney and his bot. Sidney claims he got all the information he needed from the user-friendly Pololu website at [www.pololu.com](http://www.pololu.com). While Sidney failed to place in the competition, he was elated when his bot detected, attacked, and rendered an opponent inoperative (Figure 24).

John Frizell from the United



FIGURE 27. Brazilian Beetleweight autonomous bot Carrapato.



FIGURE 28. Brazilian yellow shirt team from the University of Itajuba.



FIGURE 29. RoboGames medallion with battery-operated gears.

## TABLE 2 - ANTWEIGHT WINNERS.

	<u>JUNIOR LEAGUE</u>	<u>OPEN CLASS</u>	<u>AUTONOMOUS</u>
<u>1st:</u>	Flynn USA	The Bomb USA	Brazo De Titano Mexico
<u>2nd:</u>	War Pig USA	Dust Pandemonium USA	Wanderer United Kingdom
<u>3rd:</u>	Velociraptor USA	Captain Crunch USA	Arrow One Mexico

## TABLE 3 - BEETLEWEIGHT WINNERS.

	<u>OPEN CLASS</u>	<u>AUTONOMOUS</u>
<u>1st:</u>	Raptor 2.2 USA	Carrapato Brazil
<u>2nd:</u>	Attitude USA	Decapitron USA
<u>3rd:</u>	Grande Tambor USA	Otto United Kingdom

Kingdom and his bot Otto (Figure 25) finished in third place. United States competitor George Collins and his innovative bot Decapatron (Figure 26) took second place. Decapatron used a pair of servos and pinchers to grasp its opponent.

Brazilian first place finisher Carrapato (Figure 27) was simply unstoppable. Carrapato is a full body spinner that methodically sensed the edge of the arena and crept around eventually hitting and damaging its opponents. Carrapato is the creation of the yellow shirt Brazilian team from the University of Itajuba (Figure 28). The Brazilians compete in multiple events and bring a fleet of well-designed bots and a lot of enthusiasm to RoboGames.

A list of the Flea winners is shown in Table 1; Ant winners are shown in Table 2; and Beetle winners are shown in Table 3. The top three winners in each category received working medallions (Figure 29) made possible by a donation from event sponsor Pololu. The beautifully designed medallions featured a battery powered set of motorized gears.

While this article focuses on the Insect combat robot events, I'd be remiss if I didn't acknowledge the 2011 reigning championship team of Matt and Wendy Maxham and their heavyweight champion bot Sewer Snake (Figure 30).

Mark your calendars now and plan to spend a weekend in April at RoboGames 2013. It is an

## TABLE 1 - FLEAWEIGHT WINNERS.

<u>1st:</u>	Tiny Terror USA
<u>2nd:</u>	Vendetta Junior Australia
<u>3rd:</u>	Pocket Brazil



FIGURE 30. Matt and Wendy Maxham with their 2011 heavyweight champion Sewer Snake.

unbelievable event you have to experience in person — 682 robots from 16 countries coming together for a weekend of robotic competition. It just doesn't get any better than that! **SV**

# EVENT REPORT:

## Robot Riot Photojournal

● by Andrea Suarez

The inaugural Robot Riot Insectweight competition took place April 27-28 at the STEM Tech Olympiad in Miami Beach, FL. After 21 knock-outs, 16 robots in the drop-out pit, and 70+ intense

matches, the winners walked away with great prizes from The Robot Marketplace and FingerTech Robotics. Robot Riot was the "new kid on the block," but the excitement from the Insectweight

arena even caught the attention of spectators from the bigger 15 lb and 120 lb robots! Thank you to *SERVO Magazine* for providing free magazines for all the competitors!

SV

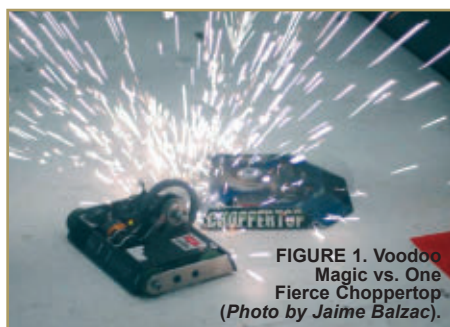


FIGURE 1. Voodoo Magic vs. One Fierce Choppertop (Photo by Jaime Balzac).

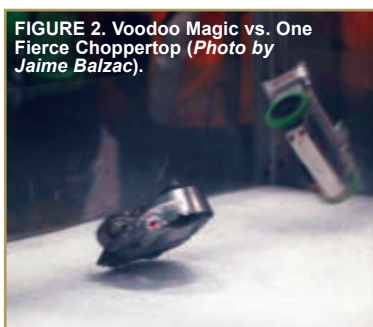


FIGURE 2. Voodoo Magic vs. One Fierce Choppertop (Photo by Jaime Balzac).

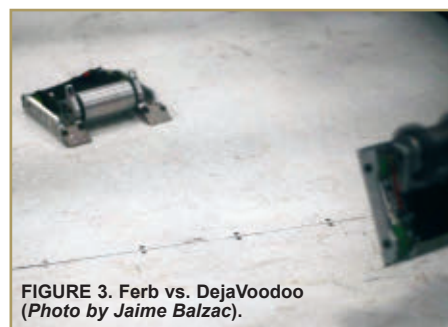


FIGURE 3. Ferb vs. DejaVoodoo (Photo by Jaime Balzac).



FIGURE 4. The 120 lb Semi Finals: TOMSO vs. Category 5 (Photo by Jaime Balzac).



FIGURE 5. Robot Riot at the STEM Tech Olympiad 2012 in Miami Beach, FL.



FIGURE 6. Chicaito vs. Mascaracachimba.



FIGURE 7. Little Scoop vs. Bar Czar.

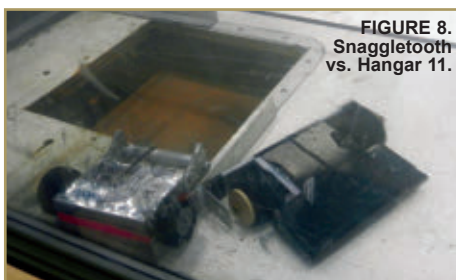


FIGURE 8. Snaggletooth vs. Hangar 11.



FIGURE 9. CNN interviews Team RoboCav.

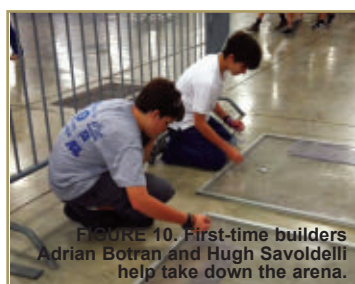


FIGURE 10. First-time builders Adrian Botran and Hugh Savoldelli help take down the arena.



FIGURE 11. Five Antweights vs. Beetleweight Chucky Norris - 2:03 on the clock and everyone is in the pit!



FIGURE 12. Firaga vs. Shazbot.



FIGURE 13. Antweight underWHERE?! wins the Beetleweight rumble!



FIGURE 14. Sidewinder vs. Lord Zipper.



FIGURE 15. The 120 lb Fluffy catches fire against full-body spinner Pandemonium.



FIGURE 16. The 120 lb Pandemonium takes on an arena full of balloons!

# EVENT REPORT:

## Robot Rumble 5

● by Pete Smith

The Museum of Life and Science in Durham, NC ([www.ncmls.org](http://www.ncmls.org)) held its fifth annual Robot Rumble event on April 14th.

This was the fourth year Carolina Combat ([www.carolinacombat.com](http://www.carolinacombat.com)) and Kitbots ([www.kitbots.com](http://www.kitbots.com)) have joined up to put on a show as part of the museum's special day. We set up the Bot Hockey arena (Figure 1) and a display of combat bots (Figure 2) as

before, but omitted the small Insect arena and combat demos, as running them and the Bot Hockey had proved just a little too much last year.

We invited members of the public to take part in short, three minute Bot Hockey matches for 30 minutes of each hour and used the remaining time to recharge the batteries and talk to anyone interested in the combat or hockey bots.

The matches proved very popular (Figure 3), but were hard on the bots. By the end of the day, we were down to only five of the original eight bots. Two were out with failed gearboxes and one had speed controller issues. We did learn one thing, though. One of



Carolina Combats bots had used the motors/gearboxes from the latest Harbor Freight #68239 cordless drills. They held up well and gave extra speed over the units from earlier drills which equipped all the other bots.



FIGURE 1. Bot hockey arena.



FIGURE 2. Combat bot display and charging stations.



FIGURE 3. Bot Hockey action.

The combat bots display attracted much attention and we handed out a lot of "Getting Started" leaflets and details of our next event to be held at the Schiele Museum in July. One person was so interested, they ordered a complete turnkey Weta Beetleweight so that they could enter that competition.

Details of these drills were in

the December '11 issue of *SERVO*.

Spreading interest in our sport has been an important part behind us getting involved in these events, and it seems that we are having some success. Museums (like the one in Durham) often run special events with a robotic or technology theme, and we have found they are keen on finding exhibitors that can add

something special to bring the crowds in.

Bot Hockey and combat robotics provide just such an attraction and the museums can provide an excellent venue. They often help in covering the expenses. If you wish to grow the sport in your area, local museums are perhaps the first place to start. **SV**

## EVENT REPORT:

### RoboGames 2012

● by Ray Billings

**R**oboGames — the largest robotic event in the world (according to Guinness World Records!) — returned to the San Mateo Exposition Center April 20th through 22nd. This annual event has become the pre-eminent event for robotics, and this year was no exception. The crowds were large and energized, and the action was non-stop.

RoboGames has been running annually in the San Francisco Bay area since 2004 (the first year it was known as the RobOlympics). The

inspiration behind RoboGames was to gather roboticists from different ideologies, and bring them together to compete at the same event. This would hopefully allow some cross-pollination, and by bringing experts

from so many differing classes together, everyone could gain some new skills in the process. This has

**Fire weapons are always a crowd favorite, and in this match both machines had flame artillery. Last year's champion Sewer Snake went on to defeat the tough wedge Raging Scotsman.**



In 60 pound lightweight action, the tough wedge of the Big B launches the full shell spinner Coroner.

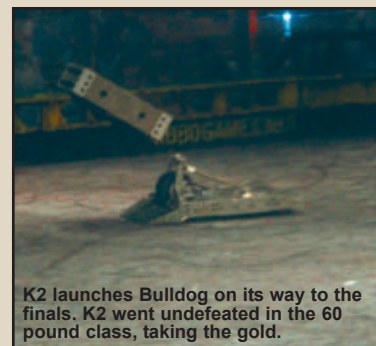




In 220 pound heavyweight action, the oversized axe of The Huntsman lays the smackdown on The Wasp.



The low wedge of Orion gives newcomer Quagadougou a ride. Orion went on to win the gold in the 120 pound middleweight class.



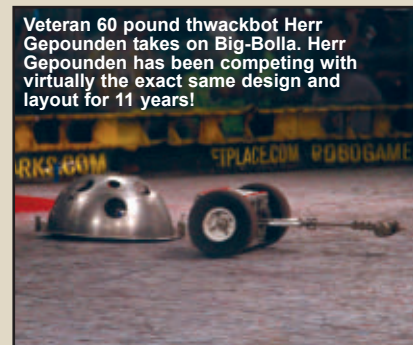
K2 launches Bulldog on its way to the finals. K2 went undefeated in the 60 pound class, taking the gold.



The vertical disks of Federal MT chewing some chunks out of Oakheart. Both of these 60 pound bots were rookie machines for this event.



Heavyweight Sewer Snake corners Gruff. Sewer Snake went on to win this match.



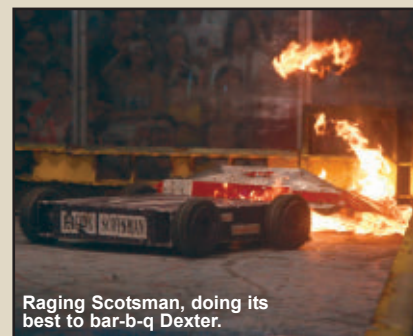
Veteran 60 pound thwackbot Herr Gepouden takes on Big-Bolla. Herr Gepouden has been competing with virtually the exact same design and layout for 11 years!



The pneumatic flipper of Spartan sends newcomer Red Robot airborne.



Original Sin takes on the spinning bar of Last Rites in quarter final action for the heavyweight class. Original Sin goes on to take the gold medal in the class.



Raging Scotsman, doing its best to bar-b-q Dexter.

created a very exciting atmosphere that keeps both competitors and fans alike coming back every year.

Robotics competitions in general are an international sport. This year's RoboGames had contestants from around the world; 682 robots from 16 different countries competed in 59 separate

events. Although RoboGames has competitions in multiple non-combat classes, it is the combat robots that garner the most attention. The larger weight classes compete in a 40 foot square arena, with action in 60, 120, and 220 pound classes. Fresh off of last year's television show on the Science Channel (look

up "Killer Robots" on YouTube), both the number of competitors and audience was higher this year.

Notably, there were several brand new machines competing which put on a great show for all. Half the robots competing in the combat classes were rookie machines, including several medal winners.

## TABLE 1.

### Combat:

	GOLD	SILVER	BRONZE
220 lbs	USA – Original Sin	USA – Electric Boogaloo	USA – Last Rites
120 lbs	Brazil – Orion	USA – Mortician	Canada – TSA Inspected
60 lbs	USA – K2	USA – Come To Mama	USA – Vortechs
3 lbs	USA – Raptor 2.2	USA – Attitude	USA – Grande Tambor
3 lbs (Auton)	Brazil – Carrapato	USA – Decapitron	UK – Otto
1 lb	USA – The Bomb	USA – Dust Pandemonium	USA – Captain Crunch
1 lb (Auton)	Mexico – Brazo De Titanio	UK – Wanderer	Mexico – ArroWar One
5.3 oz	USA – Tiny Terror	Australia – Vendetta Jr.	Brazil – Pocket

In 120 pound middleweight semi final action, the spinning bar of Mortician faced off against the almost indestructible wedge of TSA Inspected.



The stands around the combat arena were packed all three days!



Last Rites and Sewer Snake in a rematch of last year's heavyweight finals. Last Rites goes on to win this match.



In 60 pound lightweight action, veteran robot K2 with its twin vertical disks defeated several top ranked bots to claim victory. K2 went undefeated and had to beat top ranked drum bot Come to Mama twice to secure the gold in this category. Come to Mama got the silver medal, while newcomer Vortechs — a very tough and well driven wedge — rounded out the class with the bronze.

In the 120 pound middleweight class, the tough rookie wedge bot Orion went undefeated, easily taking the gold. Orion beat #1 ranked (and last year's RoboGames winner) TSA Inspected; #3 ranked Mortician; and #4 ranked Maloney on its way to victory, easily dominating the class. The always dangerous spinning bar of Mortician took this year's silver medal, with the tough wedge TSA Inspected finishing with the bronze medal.

In 220 pound heavyweight action, the incredibly stout and well



Electric Boogaloo was an all new heavyweight bot which put on a great show of power. Here it launches the tough lifter bot Gruff. Electric Boogaloo went on to take the silver medal in the heavyweight class.

driven wedge bot Original Sin went undefeated, marching its way to its fourth gold medal at RoboGames. The silver went to an all new bot — an incredible crowd favorite named Electric Boogaloo. Electric Boogaloo has an unusual and very effective one tooth design vertical disk that was putting on an incredible display of power. The always menacing (to robots and arenas alike!) spinning bar of Last Rites took the bronze medal.

**Table 1** shows the results from



Gary Gin, winning his 4th gold medal in the heavyweight class.

the combat classes (a complete list of all winners in all classes can be found at <http://robogames.net/2012.php>).

For future large scale combat action, look for the popular COMBOTS Cup event later this year, and the return of RoboGames in 2013. Full details are at [www.combots.net](http://www.combots.net) and <http://robogames.net/index.php>. **SV**

*Photos courtesy of James Darr.*

# EVENT REPORT:

## South Florida Robot Riot

● by Dave Graham

**B**usted Nuts Robotics partnered with the United States Alliance for Technological Literacy (USATL) to add an Insect class fighting robot competition to the 2012 STEM Tech Olympiad at the Miami Beach Convention Center the last

weekend in April. This was the inaugural event for the open Insect class competition officially titled the South Florida (SFL) Robot Riot. Fighting robot enthusiasts from Michigan to Puerto Rico answered the call and converged on the

convention center, with over 40 Insect class fighting robots competing in 150 gram Flea (a.k.a., Fairy), one pound Ant, and three pound Beetleweight classes. Matches were held in an eight foot square enclosed arena with a

FIGURE 1.  
Fleaweight  
bot Tomahawk.

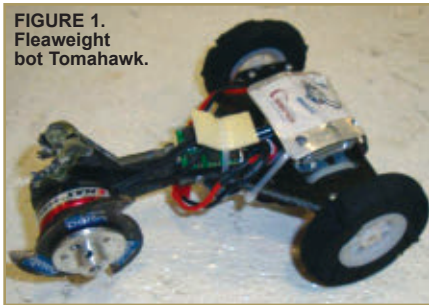


FIGURE 6. Fleaweight  
bot Hedgehog.

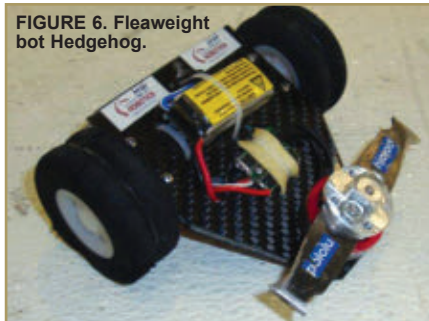


FIGURE 7. Fleaweight bot Berserker.



FIGURE 2. Fleaweight bot Twisted Fate with  
battery wire cut after match with Tomahawk.



FIGURE 8.  
Antweight  
bot Firaga.

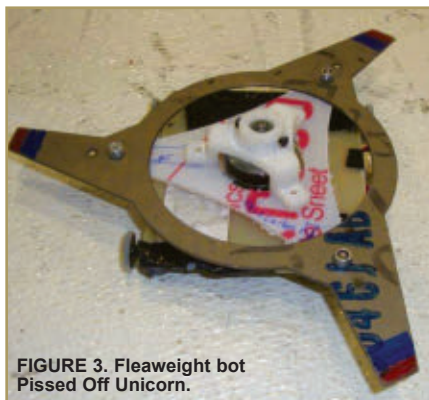


FIGURE 3. Fleaweight bot  
Pissed Off Unicorn.

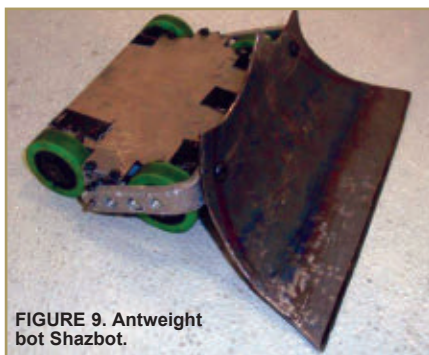


FIGURE 9. Antweight  
bot Shazbot.



FIGURE 4. Fleaweight bot Invertigo after match  
with Pissed Off Unicorn.

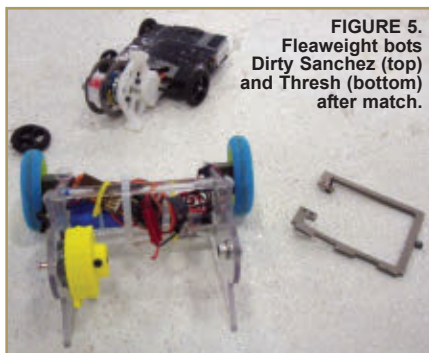


FIGURE 5.  
Fleaweight bots  
Dirty Sanchez (top)  
and Thresh (bottom)  
after match.

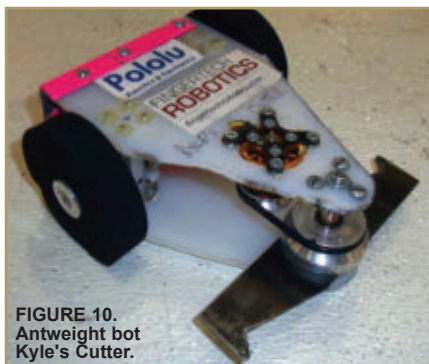


FIGURE 10.  
Antweight bot  
Kyle's Cutter.

pit in one corner. Event organizers had a unique rule in that a bot had 10 seconds to extricate itself from the pit and continue the match or to remain in the pit and be counted out. Interestingly enough, two bots managed to escape the pit.

The Fleaweight competition had a lot of crowd-pleasing action and plenty of damage as a collection of the toughest vertical spinners, wedges, horizontal spinners, a beater, and a Melty Brain full body spinner tried to destroy one another. In first round action, my vertical spinner Tomahawk (**Figure 1**) was pitted against Battlebots legend Jim Smentowski and his big horizontal spinner Twisted Fate. After the bots collided and launched each other to opposite corners of the arena, Twisted Fate was motionless. A lucky hit by Tomahawk cut Twisted Fate's battery wire (**Figure 2**).

In second round action, Paul Grata and his bot Pissed Off Unicorn (**Figure 3**) not so surgically removed the right motor, motor mount, and wheel from Busted Nuts teammate Andrea Suarez's bot Invertigo (**Figure 4**).

In the Loser's bracket, another Paul Grata bot named Dirty Sanchez lost a wheel as it ripped the beater off of Busted Nuts teammate Jennifer Villa's bot Thresh (**Figure 5**).

After five rounds of fighting, three bots remained in contention: my horizontal spinner Hedgehog (**Figure 6**); Mike Gellately's Melty Brain full body spinner Berserker (**Figure 7**); and Paul Grata's Pissed Off Unicorn. Berserker defeated third place finisher Hedgehog in the Loser's bracket to move on and meet Pissed Off Unicorn in the final match.

Coming from the Loser's bracket, Berserker would have to win two matches with Pissed Off Unicorn in the tournament's double elimination format. Berserker



FIGURE 11. Damage to Antweight bot Firaga from match with Kyle's Cutter.



FIGURE 12. Antweight bot Capricant.

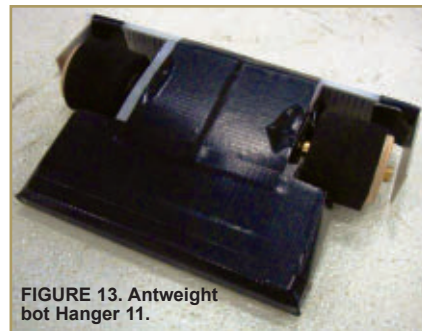


FIGURE 13. Antweight bot Hanger 11.

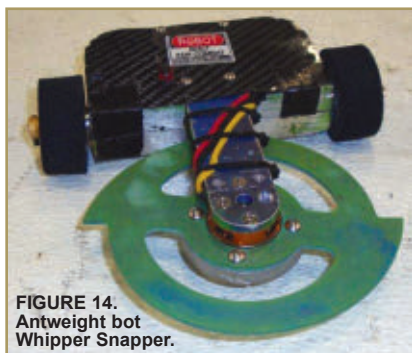


FIGURE 14. Antweight bot Whipper Snapper.



FIGURE 15. Beetleweight bot One Fierce Lawn Boy.

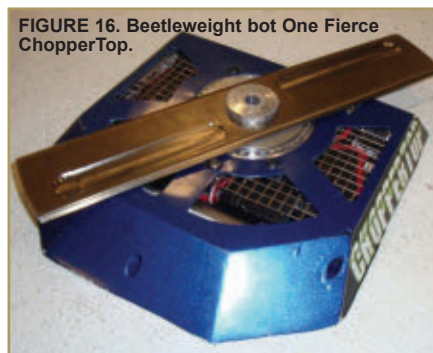


FIGURE 16. Beetleweight bot One Fierce ChopperTop.



FIGURE 17. Beetleweight bot Challenge Accepted.

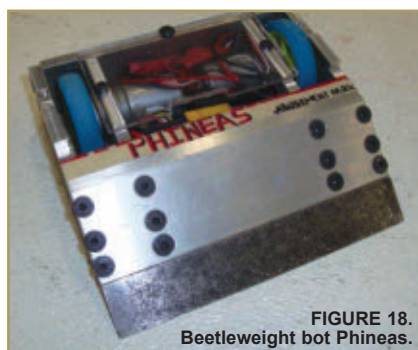


FIGURE 18. Beetleweight bot Phineas.

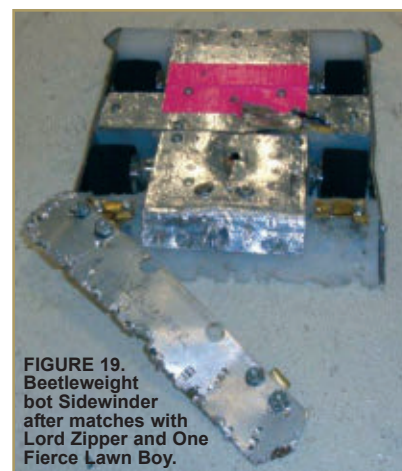


FIGURE 19. Beetleweight bot Sidewinder after matches with Lord Zipper and One Fierce Lawn Boy.

took the first match forcing a second fight. This time, Pissed Off Unicorn lived up to its name and put what appeared to be a slap shot on Berserker, launching the hockey puck shaped bot into the arena pit. Pissed Off Unicorn won a tough competition and the Flea gold.

Antweight bots toeing the line included Eric Mueller's fan favorite full body spinner Firaga (**Figure 8**), Jim Smentowski's bulldozer looking bot with an articulated blade named Shazbot (**Figure 9**), and the usual collection of spinners and wedges. In first round action, Shazbot sent Firaga to the Loser's bracket. Eric Mueller's second Ant entry Under Where sent Kyle's Cutter (**Figure 10**) to the Loser's

bracket and a match with Firaga. Kyle's Cutter ended Firaga's day two minutes into a great back and forth match when Eric lost radio contact with his bot and was counted out. After the match, Eric displayed the bite marks on Firaga from Kyle's Cutter (**Figure 11**).

Sam McAmis and his battle tested bot Capricant (**Figure 12**) was having its way with Hanger 11 (**Figure 13**), pushing it around the arena pretty much at will. Then, Sam inadvertently drove Capricant into the pit giving Hanger 11 the easy win and a berth in the Ant final match. In the Loser's bracket, Andrea Suarez ended Shazbot's run at the gold when her bot Whipper Snapper (**Figure 14**) stood

Shazbot up on its blade for a count out. Whipper Snapper lost to Capricant in the Loser's bracket final match, forcing a rematch between Hanger 11 and Capricant for the Ant gold.

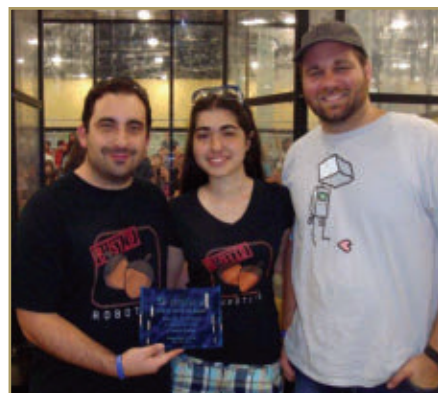
The Ant final match was pretty much a replay of their earlier match with Capricant owning Hanger 11 and pushing it around the arena at will. That was the story of the match until Capricant got too close to the arena pit again and ended up in the pit with less than 10 seconds remaining in the match to give Hanger 11 the Ant title.



**FIGURE 20.** Beetleweight bot Lord Zipper after match with One Fierce Lawn Boy.



**FIGURE 21.** Gene Burbeck and fiancée Cathi do the kiss of death.



**FIGURE 22.** Event organizers Mike Gellately (left), Andrea Suarez (center), and Paul Grata (right).

Thirteen Beetleweight bots pounded one another for bragging rights, including Gene Burbeck's two thrashing machines One Fierce Lawn Boy (**Figure 15**) and One Fierce Chopper Top (**Figure 16**); six entries from Puerto Rican high school teams Robocav and Abusement Park; and Win Halelamien's innovative bot Challenge Accepted (**Figure 17**) that used a suction pump to gain better traction on the arena floor to make his bot feel heavier than its three pounds.

In first round action, Puerto Rican Team Abusement Park's bot Phineas (**Figure 18**) sent One Fierce Lawn Boy to the Loser's bracket when One Fierce Lawn Boy lost power and was counted out. In later Winner's bracket action, Phineas sent One Fierce Chopper Top to the Loser's bracket when Phineas was able to stay under the big spinning blade and push One Fierce Chopper Top around the arena. I lost to Lord Zipper in the

opening round and to One Fierce Lawn Boy in the Loser's bracket with my bot Sidewinder. Sidewinder took a beating at the hands of the two bots (**Figure 19**).

Lord Zipper felt some of my pain after fighting One Fierce Lawn Boy in the Loser's bracket and losing a couple teeth in the process (**Figure 20**). Phineas went on to run the Winner's bracket and earn its way to the final match. Loser's bracket action saw the final match come down to One Fierce Lawn Boy and One Fierce Chopper Top. Gene opted to tap out Chopper Top sending One Fierce Lawn Boy to a final round rematch against Phineas.

Prior to every match, Gene gives his fiancée Cathi a kiss in a ritual we have termed the kiss of death for Gene's opponents. Gene and Cathi kissed (**Figure 21**) prior to the final match. This time, the kiss of death fell short as solid driving by Team Abusement Park kept the wedge of Phineas in the

face of One Fierce Lawn Boy, allowing Phineas to get under Lawn Boy, push it around the arena, and win the Beetle bragging rights in a hard fought competition. A complete list of winners is in **Table 1**.

Busted Nuts Robotics event organizers (**Figure 22**) Mike Gellately (left), Andrea Suarez (center), and Paul Grata (right) would like to thank event sponsor USATL for providing them the space at the convention center and the beautifully etched trophies; Stan Marion for providing the arena; and *SERVO Magazine*, FingerTech Robotics, and The Robot Marketplace for their prize donations.

The SFL Robot Riot is a quality event with some of the best builders, drivers, and bots in the country. You can't beat the Miami Beach Convention Center venue and staying within walking distance of the Art Deco section in Miami Beach is an added bonus.

Watch for future SFL fighting robot events and plan to attend.

I have one final good luck shout out to Gene and Cathi as they plan their August wedding. We wish them all the best! **SV**

## TABLE 1 – WINNERS.

	<b>FLEA</b>	<b>ANT</b>	<b>BEETLE</b>
<b>1st:</b>	Pissed Off Unicorn Paul Grata	Hanger 11 Hugh Marion	Phineas Team Abusement Park
<b>2nd:</b>	Berserker Mike Gellately	Capricant Sam McAmis	One Fierce Lawn Boy Gene Burbeck
<b>3rd:</b>	Hedgehog Dave Graham	Whipper Snapper Andrea Suarez	One Fierce Chopper Top Gene Burbeck

# The History of Robot Combat: RoboGames

● by Morgan Berry

*Note from the editor: Combat Zone declared 2012 "History Year," and commissioned a young writer to produce an article series attempting to pick up where Brad Stone's excellent book, "Gearheads" left off. This month, Morgan continues digging into the very raggedly documented history of our sport with this piece on RoboGames. In case you've missed other editions, she covered The Early Years in January, BattleBots in February, the post BattleBots transition in March, a comprehensive investigation into The Rise of the Ants in April, and Beetles last month.*

**A**fter the ending of BattleBots in 2003, a void was left in the world of robot combat competitions. A myriad of small competitions emerged to partially fill this void, but even with this flourishing of activity across the country, there was a noticeable absence caused by BattleBot's end. While there were some national events, nothing as large or encompassing as BattleBots was quick to take root. Recently, this has changed.

While local competitions are still active across the country, they have been majorly scaled down and are less active than they once were in the early 2000s. In many ways, the robot combat portion of the festivities at RoboGames is the current answer to BattleBots. The largest robot combat event in the United States — and even the world — RoboGames has shifted robot combat back from a small grassroots movement to a centralized sport, much like it was during the BattleBots days.

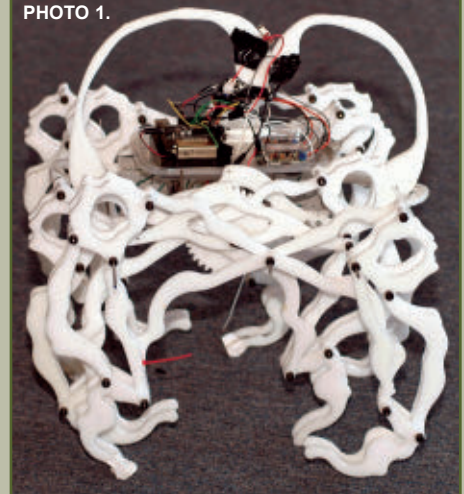
## The Beginning

It was not David Calkins' — the

founder of RoboGames — intention to create a successor to BattleBots. Calkins created RoboGames in order to foster collaboration between the different sectors of robotics enthusiasts. While participating in various kinds of robotics events, Calkins realized that roboticists tended to become extremely specialized in their particular area while ignoring all other areas. Combat enthusiasts stay in their circle, while the makers of Sumo bots (autonomous robots that use sensors to try and force the competitor out of a circular arena) also kept to themselves. The android enthusiasts, the robotic soccer programmers, and the makers of art bots also largely collaborated only with other builders from their own discipline.

Calkins saw this as a problem because although every one of those hobbies is undisputably cool, they really only rely on a few skill sets to compete. Most combat robots do not use a lot of computer programming or sensor technology to compete, while the other disciplines utilize completely different technologies during competition. Calkins began to realize that collaboration and "cross-pollination" across these different areas could make all of these already awesome sports even better. He could think of no better way to accomplish this than to create an event that brought all of these sports under one roof.

PHOTO 1.



If Sumo, soccer, and combat events were physically in the same place, the participants in these events could not help but collaborate with each other. In 2004, Calkins brought this vision to life and hosted the first RoboGames competition.

## What's in a Name?

After developing the idea, Calkins named his competition RobOlympics. Bringing together all of these different competitions in robotic sports and the inclusion of competitors from all over the world very much mimicked the human



PHOTO 2.



PHOTO 3.

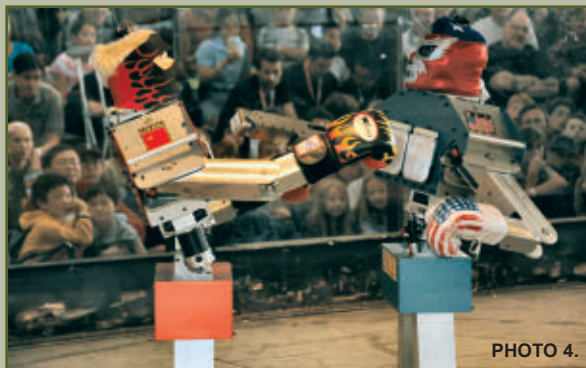


PHOTO 4.

been known as RoboGames ever since.

## The Early RoboGames Events

The initial RobOlympics competition in March 2004 saw some famous faces from the robot combat world. Trey Roski, BattleBots founder, served as a judge for the combat events. Popular 316 lb The Judge — a former BattleBot driven by father and son team Scott and Jascha Little — took home the first gold medal in heaviest weight class.

Tombstone — a successful superheavyweight designed by Ray Billings — debuted at the competition and placed second in the category. The first match Tombstone fought at the event was against a wedge called Blue Max, driven by (as best as my research can uncover) Adrian “Bunny” Dorsey. Between the blade on Tombstone and the speed of Blue Max, the safety coordinator Steve Judd and the designer of the arena Steve Brown were worried that the arena wouldn’t stand up to the power of these two bots. Parts flew across the arena, hitting the Lexan and giving the spectators and the judges quite a scare. In the end, Tombstone defeated Blue Max, and went on to take home the silver medal. Billings won another gold medal in the junior league competition with his bot The Mortician, which still competes in RoboGames to this day — winning a silver medal in this year’s event. When asked what stood out to him about the first event, Billings said, “That first event was a blast, and you could tell it was

the start of something big, something special. I’ve been to every one of them since the beginning, and I still get the feeling that it is something special every time I go.”

## RoboGames Today

Since the first years of RoboGames — where Calkins financed most of the competition himself — the event has grown considerably. According to the RoboGames website, the robot combat events draw tens of thousands of spectators. While many of the spectators are initially attracted to the event because of the combat portion, they find themselves equally enthralled with the other sports, as well. In this way, RoboGames is expanding common knowledge of robotics competitions.

Even the competitors find themselves drawn to the sports outside of their area of expertise, as Professor Marco Meggiolaro, professor at the Catholic University of Rio de Janeiro in Brazil and one of the top robot combat builders in the world, explained. Professor Meggiolaro has taken a team of students to compete in RoboGames every year since 2006. Even though he was too busy managing his team of 10 combat robots to watch them live, he watched videotapes of Sumo and hockey events — his favorite non-combat events — recorded for him by his students.

As for the cross-pollination that RoboGames tries to encourage, Meggiolaro explains that in addition to learning about different components from other competitors — such as the faster sensors used in Sumo — at RoboGames, he has also learned first-hand that “combat is the ultimate test of any component.” “For instance, we were able to blow three 200A rated (continuous-current) very high-end brushless ESCs (electronic speed controllers), which — in theory —

Olympic Games. Calkins even decided to hand out gold, silver, and bronze medals to the winning robot designers. However, two weeks before the second annual competition, RobOlympics was abruptly renamed RoboGames.

Why the sudden change? As has often been the case in the world of robot combat, legal disputes were to blame. The United States Olympic Committee (USOC) wasn’t too happy about Calkins’ choice. The USOC has a long history of strictly enforcing the Olympic trademark, going after any event using the word in their title. Despite receiving international news coverage, the first competition in 2004 went off without a hitch. Just weeks before the 2005 event, however, the USOC sent a cease-and-desist letter to the Robotics Society of America, the event’s host. San Francisco State University — afraid of legal repercussions from the USOC — threatened to cancel the event if the name was not changed. Although he was reluctant to give in, Calkins changed the name, and the competition has

were blow-proof, even using all the manufacturer's settings and protections specific to our "application," given over the phone by the owner himself. If you want to test the limit of anything, try it in our bots; we will break it or blow it!" Meggiolaro says.

Meggiolaro's RioBotz team fared well at RoboGames this year, winning medals in Sumo, combat, and solar-powered bots. Although a somewhat experienced team caused some "rookie mistakes [that] cost a few matches for Touro Light, Maloney, Touro, and even Touro Maximus this year," RioBotz still had triumphant moments. In a rematch of a 2011 loss to Biolho — a multibot from Team Kimau Ajnisso — Touro Lite had a big win, making for one of Meggiolaro's favorite moments from RoboGames. "Touro Light not only opened up both robots, popping out a few batteries from them, but also shot both of them across the entire arena to the dead zone, like a goal kick in a soccer match. It was a fun fight. The entire chassis of both Biolhos were given to us as trophies." Meggiolaro said.

Wendy and Matt Maxham — long time competitors at RoboGames — witnessed an

explosion of popular interest in the event after the Science Channel featured the combat robots from the 2011 RoboGames. "This year's RoboGames was quite different from previous years outside the arena. Sewer Snake is usually a crowd favorite with some people stopping by to ask questions about the bot. This year, however, the sheer number of people squealing "OMG — it's Sewer Snake!" was incredible. We had a steady stream of people (builders and audience members) at our pits area asking questions and for autographs. We signed trading cards, shirts, Antweight robots, even scraps of paper. By the end of Friday (the first day of competition), Matt and I were both hoarse from talking so much. Why were so many more people into Sewer Snake than in previous years? "Killer Robots: RoboGames 2011," the Science Channel show from last year's competition. Winning a televised event really brought out the fans," Wendy told *SERVO*. Another change for Wendy and Matt at Team PlumbCrazy for this year's event was



PHOTO 5.

the inclusion of a camera on Sewer Snake which provided an awesome close-up view of the fights (see photo). The videos can be found on YouTube by searching "Sewer Snake Robot."

The goal of RoboGames is to bring builders of different types of bots together, and it appears to be succeeding at this. From all over the world, some of the best combat builders come to compete in a first class competition in all weight brackets. They congregate, collaborate, and walk away with new ideas for their bots. By serving as a central hub for robot combat today, RoboGames is not only keeping the sport alive, but causing it to thrive by fostering creativity and ingenuity among the builders. **SV**

## Melty Brains

## Organ Transplants

by Kevin Berry

Doc, we found a busted bot!

Who's the donor?

Uh, it's an old FIRST bot

This is a VANTEC bot!  
It'll reject a Victor in  
a heartbeat!

Doc, the match is in 20 minutes!

OK, we'll try. Hang two bags  
of magic smoke and prep  
the IFI with cooling fans.

# Reach Out and Touch Something

## *Giving Your Robot the Sense of Feel*

by Gordon McComb

Discuss this article in the *SERVO Magazine* forums at <http://forum.servomagazine.com>

**It's not enough that your robot rumbles and bumps across the floor. You want your mechanical creation to know when something is in its way, so it'll either steer around the object, stop, or growl something scary to make the object move. Detecting stuff in front of us is easy enough for us humans, but for a robot it requires adding one or more sensors.**

**O**ne sure way to detect objects is to make physical contact with them. Sure, it sounds primitive but contact is the most common form of object detection. It's the cheapest to implement — just a buck or two to get started — and it forms the basis for the sensory network on any robot, large or small.

In this article, you'll learn about a trio of common and inexpensive touch sensor types you can add to your bot. I'll provide basic hookup examples and coding for the Arduino, but know the same concepts can be applied to any microcontroller or other control circuit. This time around, we'll introduce the sensors and how to interface them to your Arduino. Then next month, we'll demonstrate their actual use on an actual robot. Fun stuff, so let's not delay!

### Understanding Robotic Touch

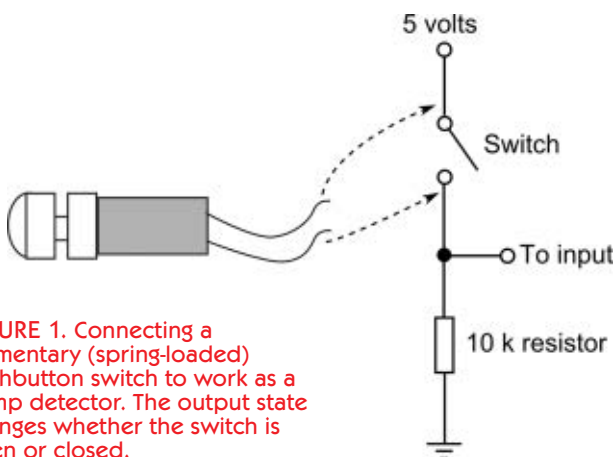
Touch lets your robot determine its surroundings by making physical contact. This contact is registered through a detector or sensor of some type which is connected to the robot's main processor or control circuit. There are a variety of touch sensors for low-cost educational and amateur bots; the most common are switch, resistive pressure, and piezo. We'll cover all three in this article.

How the robot reacts to touch is defined by its programming or wiring. The robot assesses the action (the sensor makes contact), and turns that into an action. Most often, a collision with an object causes the robot to stop what it's doing and back away. Depending on the circumstances, contact can mean other things, like your robot has found its home base, or that it's located an enemy bot and should engage in combat.

The lowly mechanical switch is the most common and most simple form of touch sensor. Most any spring-loaded (momentary) switch will do. When the robot bumps into something, the switch closes, completing a circuit.

In the typical Arduino-based robot, the switch is wired to one of the input/output pins on the microcontroller like that in **Figure 1**. The switch connection normally provides a low (zero volts) state. When contact is made, the switch closes and the output of the switch goes high (five volts). The program running in the Arduino senses this change, and knows physical contact has been made.

When using a microcontroller, you can determine how the robot reacts to the physical collision by altering its programming. With a switch used for a touch sensor, the



**FIGURE 1.** Connecting a momentary (spring-loaded) pushbutton switch to work as a bump detector. The output state changes whether the switch is open or closed.

programming typically instructs the robot to stop, back up, and head in a new direction.

A *leaf* or *lever* switch makes a very handy robot touch sensor. It sports an enclosed body with electrical contacts, and a plastic or metal strip that provides a mechanical advantage to a momentary spring-loaded pushbutton. Leaf switches require only a small touch before they trigger. As the leaf is really a mechanical lever, lengthening it increases sensitivity. However, it can also increase the distance (called throw) that the end of the lever must travel before the switch makes contact.

**Figure 2** shows a pair of leaf switches attached to the front of a robot and used as contact bumper “whiskers.” The leaf has been extended with 3” lengths of 1/4” (inside diameter) aluminum tubing found at a nearby hobby and craft store. You can also use rubber aquarium tubing; just slide it over the leaf for a snug fit. You’ll probably need to bend out the leaf to make room for the thickness of the tubing.

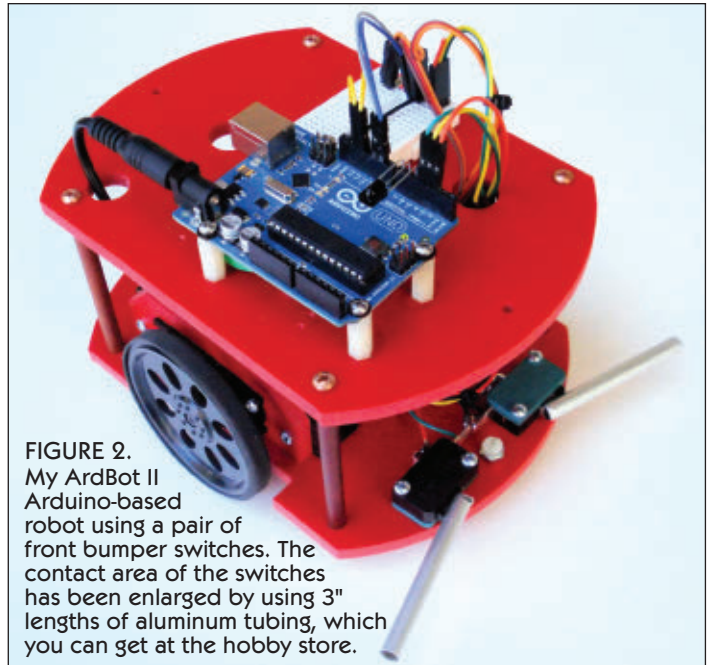
Bumper switches produce transitory events. That is, the switch closure may not occur for long periods of time — and when they do, they may not last long. You’ll need to program your microcontroller to watch for these events, so that your robot can take the appropriate action when contact is made.

There are two general approaches for programming a microcontroller for bumper contacts and other events of short duration: polled and interrupt.

- *Polling* involves periodically checking the state of any switches or other transient event sensors in your robot, while allowing the rest of your program to run. This method is acceptable as long as the main robot program allows for enough time to periodically check the state of the robot’s switches.
- *Interrupts* are handled internally by the microcontroller, and trigger by themselves. Your software need only be ready to receive the interrupt. When an interrupt occurs, programming you provide tells the microcontroller what you want to have happen.

**Listing 1** demonstrates how polling and interrupts are handled on the Arduino. To simplify things, only two switches are used: one is polled, and the other is set up for an interrupt. Two of the digital input pins on the Arduino Uno (or compatible board) may be used as a hardware interrupt. Depending on the exact model of the Arduino hardware you are using, this is usually pins D2 and D3. To try this sketch, connect one switch to pin D12 and another to D2.

The programming sets up pin D13 which has an integrated LED already on it as an output. It also attaches an interrupt to watch for any change on



pin D2 (known as interrupt 0). Ordinarily, the LED shows the value of the switch on D12. It’s off if the switch is open and on if the switch is closed. This is handled by the *poll* routine.

When the switch connected to D2 opens or closes, the microcontroller immediately branches to the *handle\_interrupt* routine which blinks the LED on and off for one second. After the *handle\_interrupt* routine is finished, the regular program resumes.

## LISTING 1 — ButtonPressDemo.

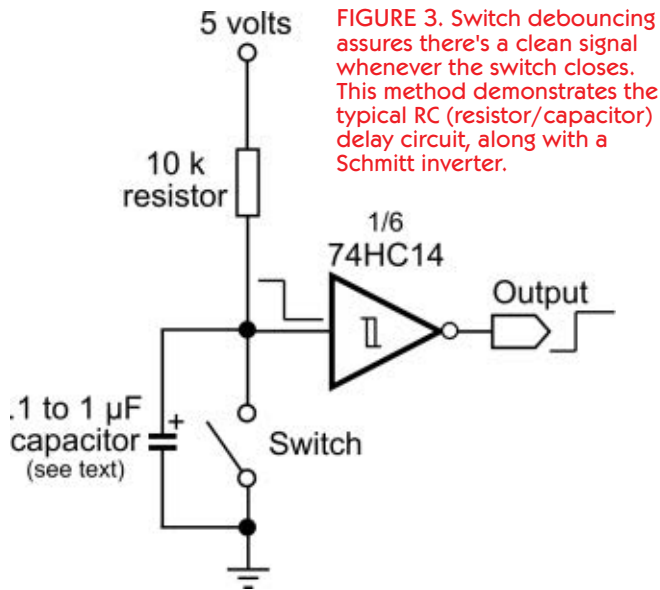
```
const int led = 13;      // Built-in LED
int bumperA = 12;       // Digital pin D12
int bumperB = 0;        // Interrupt 0 (digital pin D2)

void setup()
{
  pinMode(led, OUTPUT);
  digitalWrite(led, LOW);
  attachInterrupt(bumperB, handle_interrupt, RISING);
}

void loop() {
  // Main loop
  poll();
}

void poll() {
  // Set LED based on bumperA switch
  digitalWrite(led, digitalRead(bumperA));
}

void handle_interrupt() {
  // Interrupt handler for bumperB switch
  digitalWrite(led, HIGH);
  for (int i=0; i <= 1000; i++)
    delayMicroseconds(1000);
  digitalWrite(led, LOW);
  for (int i=0; i <= 1000; i++)
    delayMicroseconds(1000);
}
```



**Figure 3** shows a simple circuit using one-sixth of a 74HC14 Schmitt trigger buffer IC, along with a resistor and capacitor to form an RC (resistor/capacitor) timing network. Note that the 74HC14 contains inverting buffers, meaning that the polarity of the input signal is reversed on the output — low becomes high, and high becomes low. Remember this when you connect the circuit to your microcontroller.

You can also implement switch debouncing in software. In fact, many microcontrollers have programming statements for use with mechanical pushbuttons. Like their hardware counterparts, software debouncing relies on introducing a delay in the software. The short delay of 20-100 milliseconds causes the microcontroller to pause just long enough that it simply doesn't detect any of the bounces. The Arduino has a *Bounce* library available that you can download and add to your sketches. That's the most direct way to add debouncing functionality. We'll cover this technique more in-depth next time around.

## Using Multiple Switches

What happens when you have many switches scattered around your robot? You could connect the output of each switch to the microcontroller, but that's a waste of I/O pins. A better way is to use a circuit that converts many switch inputs to just a couple of control lines. One method is to use a parallel-in to serial-out shift register (PISO) — a low-cost integrated circuit that can be directly interfaced to the Arduino. Instead of needing eight pins on the Arduino for eight switches, you need only three, as shown in **Figure 4**.

**Listing 2** shows an Arduino sketch to read the switch states on a 74HC165 PISO IC, and display the current values in the Serial Monitor window. The sketch works by:

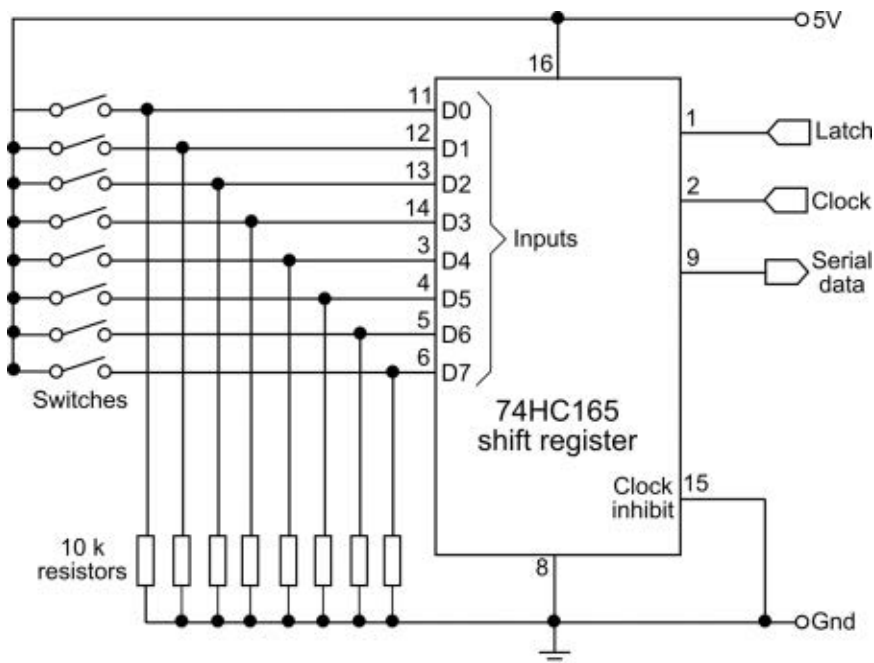
1. Momentarily setting the *latch* pin on the '165 to high; this allows the chip to read the eight switches.
2. Setting the *latch* pin low to begin reading the serial data.
3. Pulsing the *clock* pin eight times (for eight switches), while reading the low and high values coming in over the *data* pin.

The switch settings are shown in binary form in the Serial Monitor window, where 0 means the switch is open, and 1 means it's closed. For example, 01110001 means the number 2, 3, 4, and 8 switches are

## Debouncing Switch Input

Contacts in a switch don't just immediately open or close once when the switch is activated. There may be dozens of tentative transitions each time the switch changes state. This is called *bounce*. The bounces are a kind of electrical noise that can influence the operation of your circuits and programming.

There are numerous ways to remove the extra bounces when a switch opens or closes. They all operate on the principle of stretching the duration of the first switch event that occurs. Most bounces are less than 10 or 20 milliseconds (often much shorter than that, depending on the switch). So, by stretching out the switch change, all the other bounces that come after are simply missed.



**FIGURE 4.** Here's how to connect up to eight switches with a parallel-in to serial-out (PISO) shift register integrated circuit. This helps you reduce the number of I/O pins required when using multiple switches.

closed. The bits are in D0 to D7 order. That is, the left-most bit indicates the current status of the switch connected to pin 11 of the 74165 chip. The switch states are stored as an eight-bit value in the *dataStore* variable. Use this variable for any additional processing. If *dataStore*>0, then you know at least one switch is closed. Use *getBit* (or similar Arduino programming statement) to determine which switch is closed.

## Adding Mechanical Pressure Sensors to Your Robot

A switch is a go/no-go device that can detect only the presence of an object, not the amount of pressure on it. A pressure sensitive detector senses the force exerted by the object onto the robot, or vice versa — how hard the robot crashed into something. Since pressure sensors provide a varying value of some type (usually resistance or voltage), it must be connected to a converter circuit. Fortunately, the Arduino makes this easy by having its own analog signal converter built in.

The most common and inexpensive pressure sensor is the force sensing resistor. The sensor provides a remarkably accurate measurement when a given pressure is exerted onto its surface. The electrical output of a pressure sensor is a variable resistance, so it can be used in a simple voltage divider circuit like the one in **Figure 5**. You'll want to experiment with a higher or lower value for the fixed resistor on the bottom. The output of the sensor connects to one of the Arduino's analog input pins, and appears there as a varying voltage.

Force sensitive resistors consist of a main pad that forms the sensing element. The pad comes in various shapes and sizes. For use as a robot fingertip, for example, you can opt for a small 5-10 mm pad. For use as a robot bumper to detect collisions, you may want to go with a larger pad.

A variation on the force sensitive resistor is the flex resistor. They are very similar in operation, but in a flex resistor the sensing pad is greatly elongated. This makes it more sensitive to the effects of bending or twisting. Flex sensors make an ideal bumper detector on the front of your robot.

Reading the value of resistive sensors requires only a few lines of code. Here's a complete Arduino sketch

## LISTING 2 – ShiftRegisterDemo.

```
// Define how the 74165 is connected to Arduino
const int dataPin = 11;    // Pin 9 of 74165
const int clockPin = 12;   // Pin 2 of 74165
const int latchPin = 13;   // Pin 1 of 74165

int tempStore = 0;
int dataStore = 0;

void setup() {
  Serial.begin(9600);
  pinMode(dataPin, INPUT);
  pinMode(clockPin, OUTPUT);
  pinMode(latchPin, OUTPUT);
}

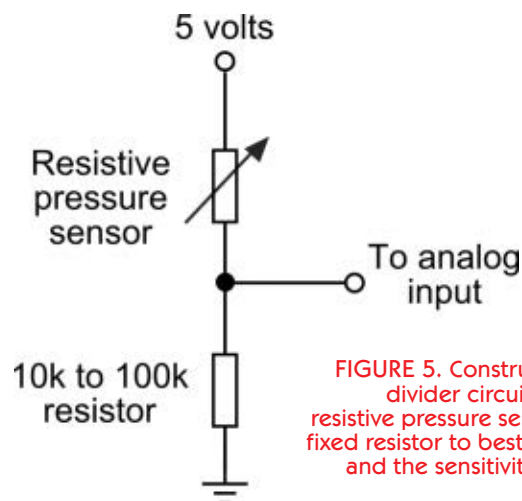
void loop() {
  shiftIn_165();           // Call shift function
  delay(250);              // Wait 1/4 second, then repeat
}

void shiftIn_165() {
  dataStore = 0;           // Store bits here

  digitalWrite(latchPin, 0); // Load data on parallel lines
  delayMicroseconds(10);     // Short wait
  digitalWrite(latchPin, 1); // Set to read

  for(int i=0; i<=7; i++){ // Cycle through all 8 bits
    digitalWrite(clockPin, 0);
    tempStore = digitalRead(dataPin);
    if(tempStore)           // If bit is a 1
      dataStore = dataStore | (1 << i); // Shift bits into place
    digitalWrite(clockPin, 1);
  }
  binaryPad(dataStore, 8); // Display in Serial Monitor
}

// Pad binary numbers with zeros,
// print result in Serial Monitor window
void binaryPad(int number, int bits) {
  int pad = 1;
  for (byte i=0; i<bits; i++) {
    if (number < pad)
      Serial.print("0");
    pad *= 2;
  }
  if (number == 0)
    Serial.println("");
  else
    Serial.println(number, BIN);
}
```



**FIGURE 5.** Constructing a voltage divider circuit for use with a resistive pressure sensor. Select the fixed resistor to best suit the sensor and the sensitivity of the circuit.

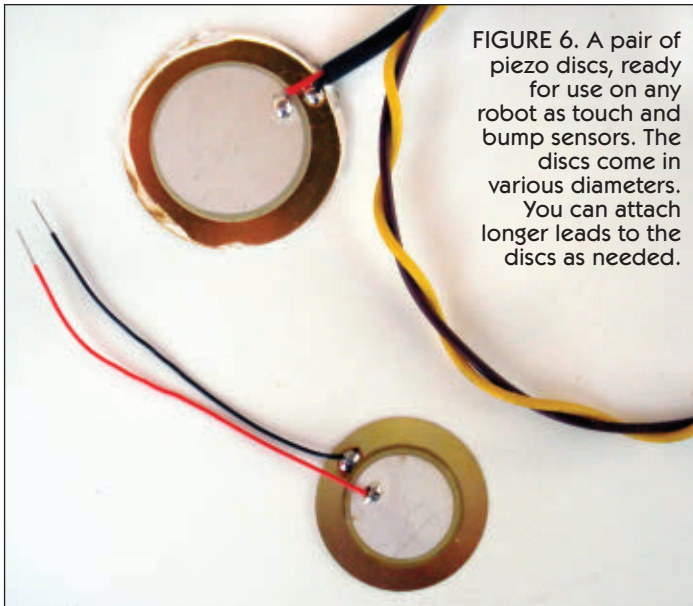


FIGURE 6. A pair of piezo discs, ready for use on any robot as touch and bump sensors. The discs come in various diameters. You can attach longer leads to the discs as needed.

While natural crystals were the first piezoelectric materials used, synthetic materials have been developed that greatly demonstrate the piezo effect. The ubiquitous ceramic piezo disc is perhaps the easiest form of piezoelectric transducer to experiment with. A sample disc is shown in **Figure 6**. The disc is made of nonferrous (no iron) metal. A ceramic-based piezo material is applied to one side. Most discs available for purchase are made for use as small speakers or buzzers. They have two leads already attached. The black lead is the “ground” of the disc and is usually directly attached to the metal rim.

When the piezo material of the disc is under pressure — even a slight amount — the disc outputs a voltage proportional to the amount of pressure. This voltage is short lived. Immediately after the initial change in pressure, the voltage output of the disc will return to zero. A negative voltage is created when the pressure is released or the disc is deformed in the opposite direction.

Some important aspects about piezo discs:

*Piezoelectric materials are voltage sensitive.* This means the more force you exert on a piezo element, the higher the voltage it will produce. That’s nice, as you can use it to determine relative force of impact. However, it also means that you need to protect your electronic circuit by limiting the volts it gets from a piezo element. While many microcontrollers — including the Arduino — contain clamping diodes on their input pins to limit voltage, it’s still considered a good idea to add external circuitry to keep the voltages to a safer level.

*Piezoelectric materials act as capacitors.* This means they can develop and retain an electrical charge. This alters the readings from the sensor, introducing error. The easiest way to counter this effect is to add a resistor across the terminals of the piezo disc.

*Piezoelectric materials are bipolar.* Press down and the material produces (for example) a positive voltage. Release and the material produces a negative voltage. These negative voltages can harm some kinds of electronic inputs. The clamping diodes on the Arduino’s input pins likewise are designed to reduce the possibility of damage in the event of negative voltages. Nevertheless, you may still wish to add your own external protective circuitry.

that reads the voltage produced by the circuit in **Figure 5** on analog pin A0 every 100 milliseconds. Open the Serial Monitor window to see the values. Press (or flex) the sensor and watch the values change, which will be over a range of 0 to 1023. A value of 0 indicates no voltage, and 1023 means five volts. You may not get the full 0-1023 range. Experiment with the value of the fixed resistor:

```
// sensor connected to analog pin A0
const int sensor = A0;

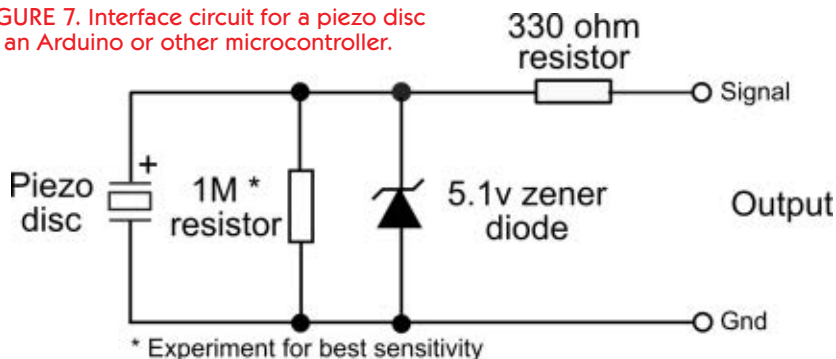
void setup() {
  Serial.begin(9600);
}

void loop() {
  Serial.println(analogRead(sensor), DEC);
  delay(100);
}
```

## Adding Touch with Piezo Elements

A new form of electricity was discovered by Pierre and Jacques Curie when they placed a weight on a certain type of crystal. The strain on the crystal produced electricity. The Curie brothers coined this new discovery “piezoelectricity;” *piezo* is derived from the Greek word meaning “press.”

FIGURE 7. Interface circuit for a piezo disc to an Arduino or other microcontroller.



**Figure 7** shows one of many ways to construct a piezo disc interface circuit. It consists of a resistor with a high value wired across the connections of the disc, a 5.1 volt zener diode, and an in-line current-limiting resistor. The output of the piezo sensor is a voltage, limited to a range of about zero to five volts. The harder the piezo disc is pressed or struck, the higher the voltage. Connect the signal output of the disc interface to any

Arduino analog pin. The following short sketch demonstrates reading the value of the disc every 50 milliseconds:

```
// Piezo disc connected to analog pin A0
const int piezo = A0;

void setup() {
  Serial.begin(9600);
}

void loop() {
  Serial.println(analogRead(piezo), DEC);
  delay(50);
}
```

Run the sketch, place the disc on a table, open the Arduino Serial Monitor window, and tap the disc with varying amounts of force. In operation, the *analogRead* statement converts the voltage present on pin A0 of the Arduino to a value from 0 (no volts) to 1023 (five volts). Try pressing against the disc and holding it down. You will note that the voltage is only fleeting. Even though you are still applying pressure, the voltage output soon disappears. This is the nature of piezo materials.

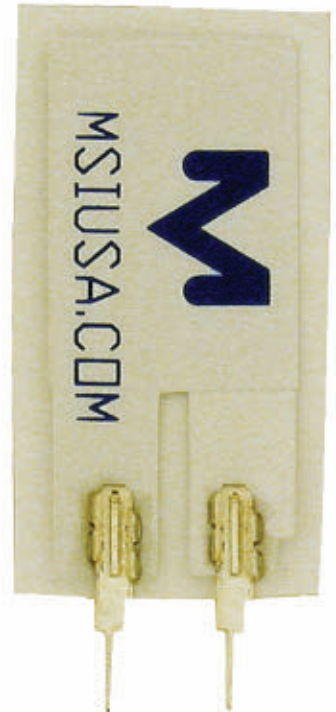
Another type of piezo sensor is piezo film, which is available in a variety of shapes and sizes. The film wafers — which are about the same thickness as paper — have two connection points, as illustrated in **Figure 8**. Like ceramic piezo discs, these two connection points are used to connect the film to your interface circuit.

You can use piezo film to sense vibration, shock, touch, and pressure — everything you can do with a piezo disc you can do with film. **Figure 9** provides a simple circuit for detecting when piezo film is struck or bent. It's similar to the interface for the piezo disc. Added is a small ceramic disc capacitor to help eliminate spurious signals (the capacitor may or may not be required depending on your wiring and application; you can try it both ways). Select a different value to experiment for best sensitivity.

Create a workable touch sensor by attaching one or two small piezo film transducers to a thick piece of plastic. The plastic membrane could be mounted on the front of a robot to detect touch contact, or even in the palm of the robot's hand. Any flexing of the membrane causes a voltage change at the output of one or both piezo film pieces. In the next article, I'll demonstrate using such a bend sensor bumper on a robot.

Use the same demonstration sketch as the one for piezo discs above. In practice — and depending on the film you use — the value only goes from 0 to about 300 when using the standard 0-5 volts analog-to-digital converter (ADC) reference (the Arduino lets you set a different reference, but this demo works fine for our purposes). In a working program, you might ignore any values under some minimal threshold (say, five or 10), and have your robot react to anything above that as an

**FIGURE 8.** Piezo film sensor, with connection terminals already provided. Photo courtesy Parallax, Inc.



indication of collision with some object:

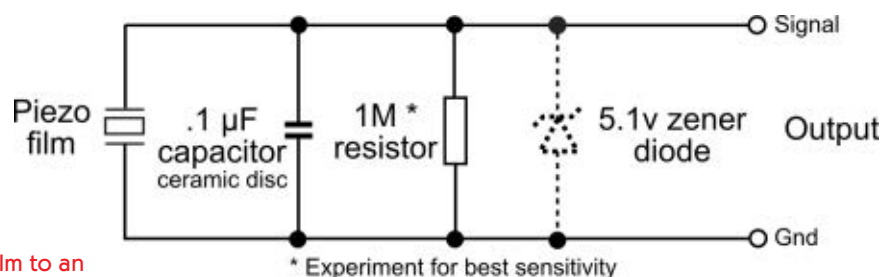
```
// Piezo film connected to analog pin A0
const int filmSensor = A0;

void setup() {
  Serial.begin(9600);
}

void loop() {
  Serial.println(analogRead(filmSensor), DEC);
  delay(500);
}
```

Recall that piezo film produces both positive- and negative-going signals. However, the ADC on the Arduino only registers positive voltage change. Depending on how the film is oriented on the plastic, you may get a higher span of readings by reversing the connections of the film to the interface circuit.

Now that you know about the more popular ways to provide touch sensitivity, you can add any — or even all — of them to your robot. That's exactly what we'll do next time around. You'll see how to integrate several of these sensor types to a small desktop robot, giving it the ability to detect objects and navigate around them. **SV**



**FIGURE 9.** Interface circuit for a piezo film to an Arduino or other microcontroller.

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# Virtual Sensors

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## Part 1

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by John Blankenship and Samuel Mishal

Discuss this article in the *SERVO Magazine* forums at <http://forum.servomagazine.com>  
[www.servomagazine.com/index.php?/magazine/article/july2012\\_Blankenship](http://www.servomagazine.com/index.php?/magazine/article/july2012_Blankenship)

In order to perform properly, your robot needs as much sensory data as possible. Unfortunately, increasing the number of sensors on your robot has many potential problems. Mapping the analog information from more complex sensors into virtual digital states can decrease costs, increase performance, and make the sensory data easier to analyze.

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**H**ave you ever wanted to add a few new sensors to your robot, and found you couldn't do it because you were a few I/O pins short? Does your robot take too long to scan the area in front of it because its rotating turret is too slow? These are only some of the problems we had to solve while finding a painless way to seamlessly connect a wide variety of sensors to RobotBASIC. Our final solution is a RobotBASIC Robot Operating System (RROS) that can manage all the details (both hardware and software) of interfacing with a wide variety of motors and sensors.

While developing the RROS, we created a number of innovative solutions to the problems we were facing — solutions that many non-RobotBASIC users can apply to

their robot. One of the most interesting of these innovations is the creation of virtual sensors. Before we delve into the details of creating virtual sensors though, let's examine sensors in general.

In the book *Robot Programmer's Bonanza*, we demonstrated — using a robot simulator — that perimeter sensors organized in a two-level hierarchical structure make it easier to implement autonomous navigation behaviors through cluttered environments. Let's start by examining that structure.

The outermost layer of our two-layer design typically consists of five IR reflective proximity sensors as depicted in **Figure 1**. These sensors should detect obstacles before any contact with the robot is actually made. The inner layer (also shown in **Figure 1**) provides a last-ditch safety arrangement that we implemented with four contact bumpers. The proximity sensors detect objects that are close, while the bumper sensors indicate when objects are very close. Combining these two systems with a turret-mounted, distance-measuring ranging sensor provides an enormous amount of sensory information that is still very easy to analyze.

Realizing such a design on a simulated robot confirmed its usefulness, but creating a real world implementation has its challenges. First, at least 11 I/O lines are needed (four bumper, five proximity, one ranger input, and one turret

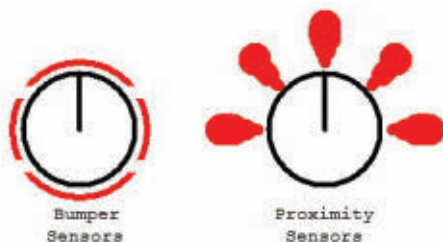


FIGURE 1.

control). Another potential problem is the time needed to rotate the turret before a distance measurement can be taken. Also, bumper sensors are notoriously difficult to physically construct — especially if they must reliably detect collisions from every possible direction. Finally, reflective sensors generally have a fixed detection range making it difficult to reconfigure the sensor's attributes on-the-fly.

## A Virtual Sensory System

Our solution to these limitations was to implement a Virtual Sensory System (VSS) using six ranging sensors. Five of the rangiers are mounted just like the proximity sensors shown in **Figure 1**. The sixth is mounted at the rear of the robot, pointing directly backward as shown in **Figure 2**. Two specified distances (let's call them *short* and *long*) can be used to extract both bumper and proximity data from the ranger readings.

For example, if the ranger labeled 1 (on the right side of the robot) measures the distance to an object closer than the *long* distance, it will be reported as a proximity sensor detection. If the distance recorded is less than *short*, a bumper collision is also indicated. Since the sensors being reported are virtual, you have complete flexibility as to how they are implemented. We decided that our RROS, for example, would report a front bumper collision when ranging sensor 2, 3, or 4 detected an obstacle within the *short* distance. Alternatively, of course, you could choose to equate only sensor 3 with the front bumper.

Since the *short* and *long* detection levels can be altered at any time, the robot can constantly change how it "sees" its environment. Perhaps the normal mode could assume the detection levels to be relatively long until objects are detected within that range. The robot can then assume a new posture depending on the task to be executed. For example, the settings for simply avoiding objects might differ from those needed to hug close to an object while transversing around it.

The soon-to-be-released RobotBASIC Robot Operating System is designed to make building a robot easier than ever. It provides both the hardware connections and the software drivers for interfacing a wide variety of motors and sensors with RobotBASIC. The interface itself is just the beginning though, because as with any operating system the RROS truly *manages* the resources being controlled. For example, it can seamlessly map the data obtained from any of the sensors discussed in this article (as well as many others), so the information can be utilized with standard RobotBASIC commands and functions. If you are curious about the features of our RROS, a draft of the *User's Manual* can be downloaded from [www.RobotBASIC.com](http://www.RobotBASIC.com).

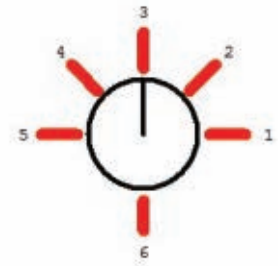


FIGURE 2.

## A Virtual Turret

With multiple ranging sensors, a turret-mounted ranger is no longer needed because software can automatically extract distance data from the ranging sensor most closely aligned with the desired direction. Since a moving turret is not required, the area in front of the robot can be quickly scanned and evaluated — perhaps even providing information helpful for determining appropriate values for the *short* and *long* detection levels associated with the perimeter sensors.

Since six ranging sensors can implement virtual versions of four bumpers, five proximity detectors, and a turret mounted ranger, we get a functionality that would normally require 11 I/O pins. Our VSS implementation requires only six pins though, making it far more efficient in this respect.

## Many Choices

When building a VSS, you have many options when it comes to what ranging sensors to use. Small robots might do better with IR ranging sensors because false readings from floor reflections are less likely. A good choice in such cases could be a Sharp analog sensor available from Pololu (shown in **Figure 3**).



FIGURE 3.

# Virtual Sensors



FIGURE 4.

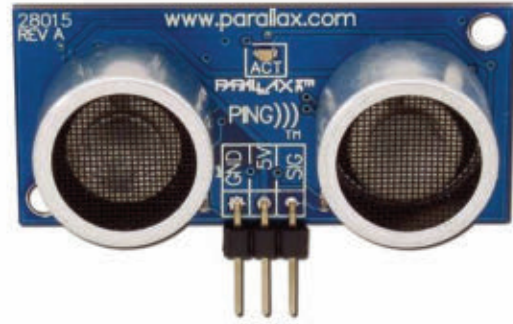


FIGURE 5.

Larger robots might benefit from ultrasonic sensors because they have a wider detection cone than IR devices. Maxbotix ultrasonic sensors (as shown in **Figure 4**) can be interfaced serially, digitally, or with an analog-capable input pin. Another advantage of the Maxbotix sensors is that they have models with various detection cone shapes.

Another viable option is the Ping))) SONAR sensor from Parallax, as shown in **Figure 5**. It can require more low-level programming than other options, but since you are doing your own programming you can do a few tricks that can greatly speed up the readings. Our RROS, for example, triggers all six Ping))) sensors simultaneously, then uses one

programming loop to watch all six sensors for their return signals, providing a six-fold speed improvement over reading each sensor independently.

The ability to create the same virtual data from any of the above sensors is a major feature of our upcoming RobotBASIC Robot Operating System because it allows a wide variety of sensory configurations to appear exactly the same to the user's application. An appropriate use of subroutines or class structures built with the techniques discussed here can help you create reusable code for your robotic projects, too.

## Vision Systems

With the right skills, you can create a Virtual Sensory System far more advanced than anything discussed so far. Assume, for example, that you are building your own sensory system that utilizes a camera instead of individual IR or ultrasonic elements. Once your software determines where objects are located in relationship to the robot, it would be a simple matter to map that information into bumper, proximity, and range data. Such a translation would also make it much easier for application programs to react to their environment because they would not have to analyze the enormous amounts of data associated with an image. Once you decide to try innovative approaches, always look for additional opportunities. For example, a little extra software could allow your vision system to create virtual line sensors or perhaps some unique sensor your robot might need for a special application.

Virtual sensors are not totally perfect, though. Ranging sensors do cost more than simple digital reflecting sensors, and it does take more CPU time to read them compared to digital sensors. After you consider all the advantages though, perhaps the next time you start a project you will consider giving your robot a few virtual sensors.

Next month, we will examine how we created virtual motor interfaces for our RROS in order to reduce the I/O pin requirements while making each interface indistinguishable from the others. **SV**

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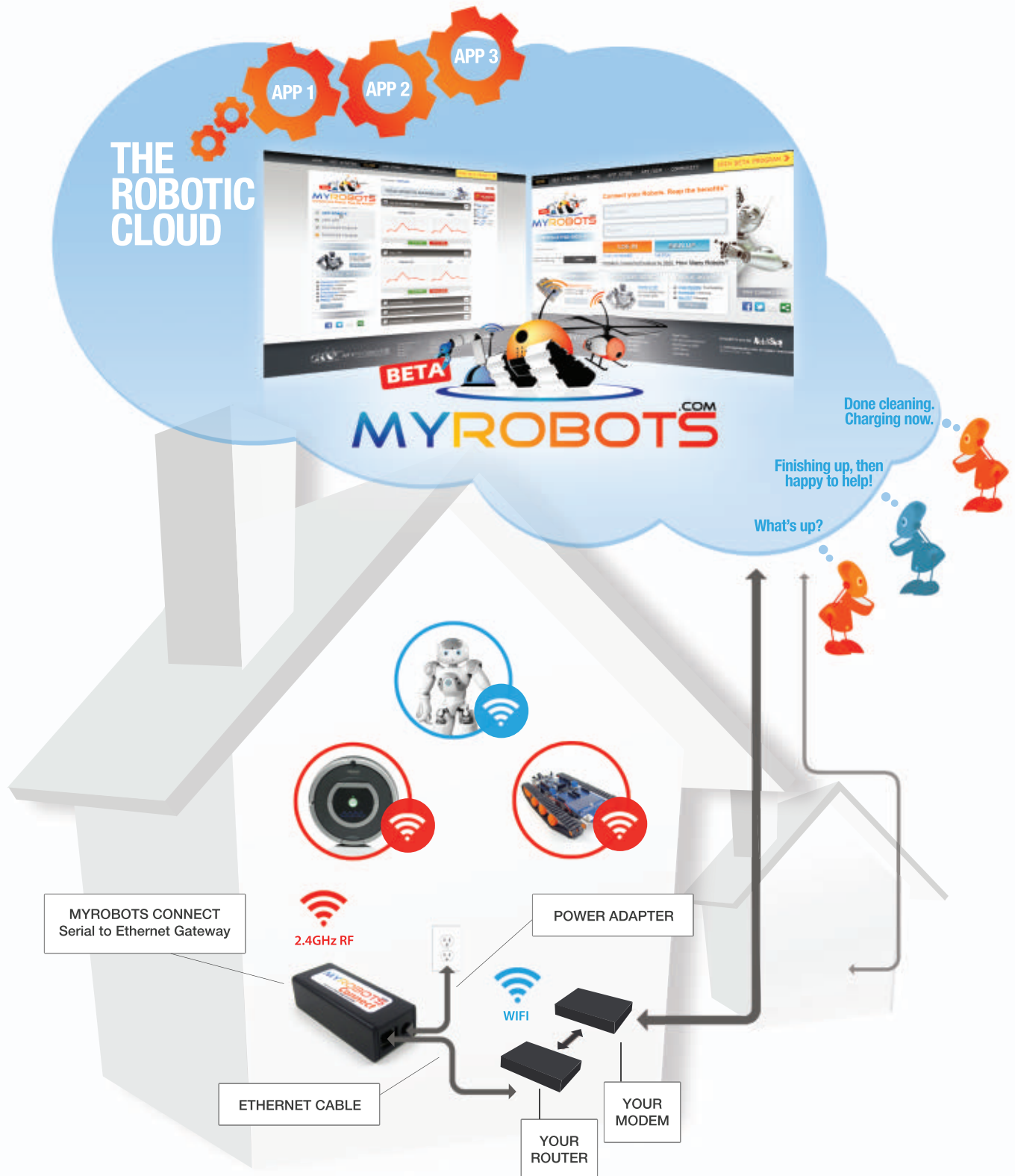
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# Using Advanced Sensors With VEX — the Peltier Effect

By Daniel Ramirez

Discuss this article in the *SERVO* Magazine forums at <http://forum.servomagazine.com>.

The Peltier Effect sounds like it should be the title of a Sci-Fi film. Movies like *Frankenstein*, *The Man in the White Suit*, and, of course, *The Absent Minded Professor* and *Son of Flubber*, were actually full of technological wonders for their time, with various lighting effects and sparks generated from Tesla coils, Van de Graff generators, Jacob's Ladders, and also for the bubbling chemicals in beakers and glass tubes in all kinds of shapes and colors.

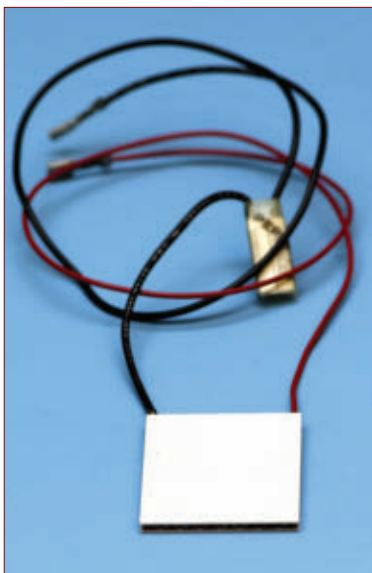
In this issue, we are going to continue where we left off from the previous installment in May by investigating the Peltier Effect and continuing to use the LM34 temperature sensor to learn more applications for it. We will utilize a heat pump that's commonly used for air conditioning with the LM34 functioning as a thermostat.

HVAC (heating, ventilation, and air conditioning) refers to the systems that provide comfort in areas where temperature sensing plays an important role. Heating homes and monitoring stoves and hot water heaters, for example, all require a thermostat to control the temperature. The same goes for air conditioners, refrigerators, and freezers.

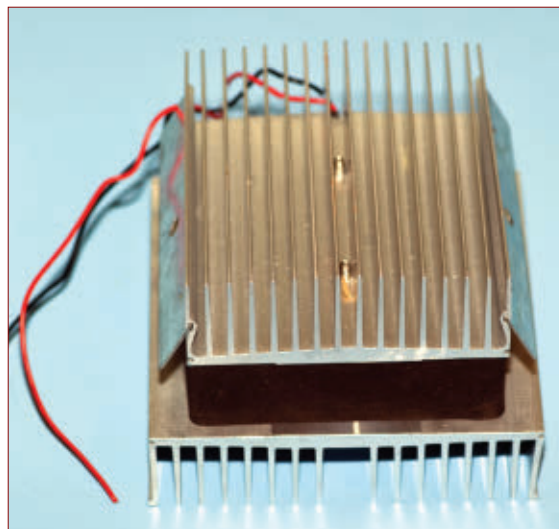
We can control the temperature of a heating pad, as we

will see below. This pad will be useful (especially in a high school or college lab) when precise temperature control is needed for an experiment. I'll show you how to obtain precise heating and even cooling of liquids using some inexpensive components, with VEX orchestrating the entire process.

Standard lab gas-powered Bunsen burners do not have very accurate temperature control. In order to incubate samples in food processing, biology, and medicine, accurate temperature control is needed. Otherwise, the samples can be destroyed. Think of the heating thermostat in an aquarium. The tropical or cold water fish depend on a specific range of temperatures. If these are exceeded, then they will suffer. The same goes for us humans.



**FIGURE 1.** This is what a Peltier heating/cooling pad looks like.



**FIGURE 2.** These TEC pads are stacked into this assembly which generates more heat; it can also cool to lower temperatures than can be accomplished using a single pad.

## What is the Peltier Effect?

The Peltier Effect is used in heat pumps for heating and cooling applications. Thermoelectric cooling uses the Peltier Effect to create a heat flux between the junctions of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active device which transfers heat from one side of the device to the other (against a temperature gradient from cold to hot) when current is passed around the circuit. We will explore both heating and cooling applications of a Peltier device in the two experiments described here. The Peltier Effect is

also related to the Seebeck Effect which was described in the May '12 issue for thermocouples except that instead of generating a voltage, current is applied to the pad which, in turn, cools one side of the pad while heating the other.

Peltier thermoelectric modules (shown in **Figure 1**) are small, lightweight, and silent devices. They use solid-state technology and have no moving parts. The modules serve either as a heat pump or as an electrical power generator. If the Seebeck Effect is used to generate electricity, the module is known as a Thermoelectric Generator (TEG). The Seebeck Effect describes the process of converting temperature differences into electricity. Conversely, if the Peltier Effect is used to pump heat, the module is known as a Thermoelectric Cooler or TEC. This technology is commonly used in a variety of industrial applications. They are also used to cool CPUs of some very fast PCs and laptops. There are many commercial applications where these modules serve as heating or cooling devices, such as portable refrigerators, processor cooling pads, and car air-conditioning and heating.

Now that we can measure temperature accurately using the LM34, it is time to use it for more practical applications, including showing how a thermostat works. We will also use a Peltier heating/cooling assembly made from multiple TECS that are stacked into the assembly shown in **Figure 2**. It generates more heat and cools to lower temperatures than using a single pad. The smaller fins on top are the heating elements and the larger fins underneath are the cooling elements.

## VEX Peltier Heat Pump Experiment

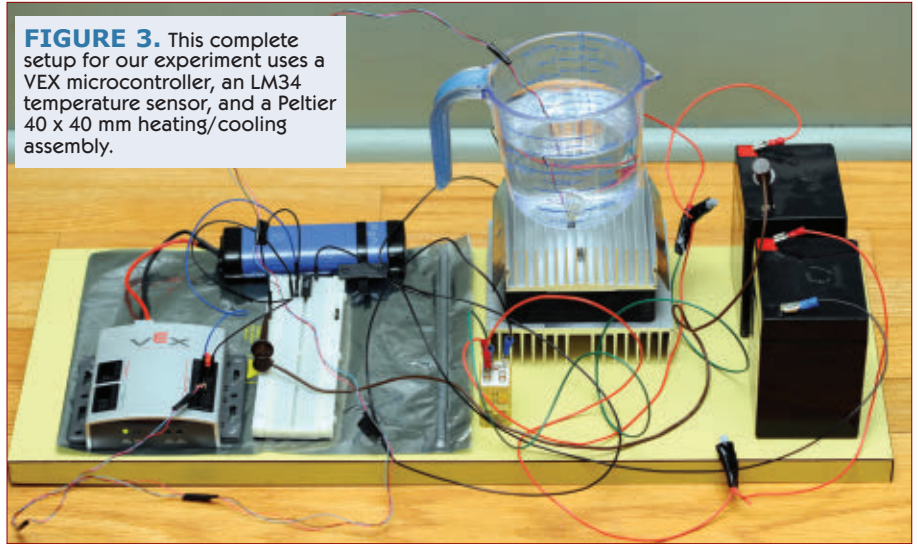
In this experiment, we will use a VEX microcontroller, an LM34 temperature sensor, and a Peltier 40 x 40 mm heating/cooling assembly as our electric temperature-controlled lab heater as shown in **Figure 3**. For best results, use a small glass beaker, measuring cup, or small tin can. In this case, we will use the Peltier heating/cooling pad to maintain a cup of water at a specific temperature as measured by the LM34 which is acting as a thermostat.

The hot side of the heating/cooling pad should be facing up for this experiment. The microcontroller is used to monitor and collect temperature readings of the heating/cooling pad and maintain it at a specific temperature (set-point).

## Bill of Materials

The Bill of Materials needed to carry out the experiment is shown in **Table 1**. The Peltier heating/cooling assembly can be purchased from All Electronics for around \$35. We

**FIGURE 3.** This complete setup for our experiment uses a VEX microcontroller, an LM34 temperature sensor, and a Peltier 40 x 40 mm heating/cooling assembly.



also need a 12 volt relay to switch the pad on or off and a ULN2803 high voltage driver IC, along with two or three rechargeable 12 volt SLA batteries. These are low cost surplus batteries recycled from old UPS and alarm systems. They can also be purchased new from All Electronics for around \$12.50. Use a 12 volt battery charger to keep them charged above 12 volts.

## The Circuit

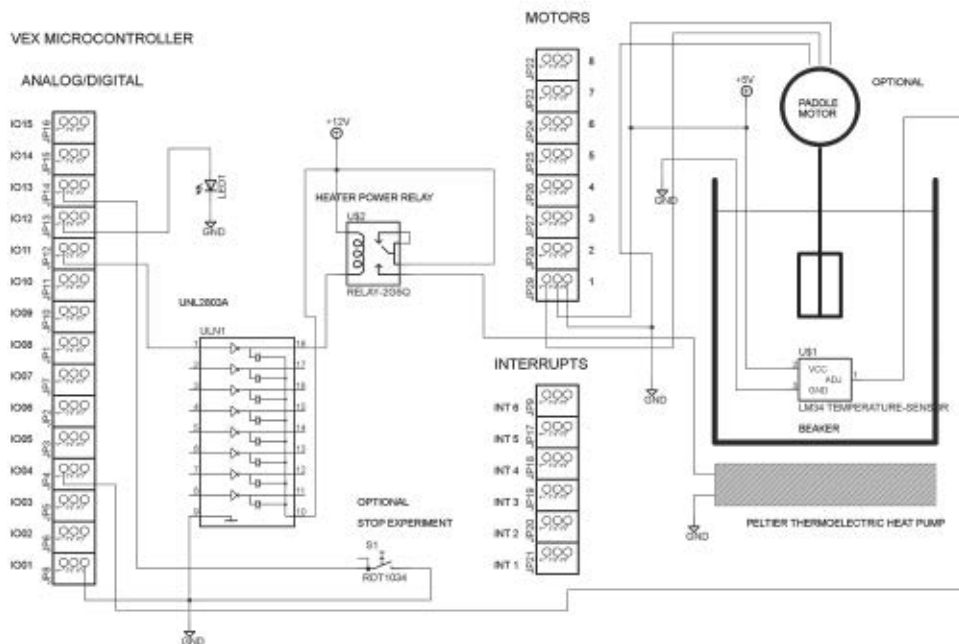
The schematic which shows you how to wire up the electronic components is shown in **Figure 4**. The LED lets us know when the heater is turned on/off and the optional switch is used to start/stop the experiment. The ULN2803

**TABLE 1.** Bill of Materials for the VEX Peltier experiments.

QTY	DESCRIPTION	SOURCE
1	VEX microcontroller	Innovation First, Inc. (IFI) <a href="http://www.vexforum.com">www.vexforum.com</a>
1	7.2 volt battery	Innovation First, Inc. <a href="http://www.vexforum.com">www.vexforum.com</a>
1	Wire-wrap cable	RadioShack <a href="http://www.radioshack.com">www.radioshack.com</a>
1	*12 volt muffin fan	All Electronics <a href="http://www.allelectronics.com">www.allelectronics.com</a>
1	VEX pushbutton	Innovation First, Inc. <a href="http://www.vexforum.com">www.vexforum.com</a>
1	Red LED	RadioShack <a href="http://www.radioshack.com">www.radioshack.com</a>
1	LM34 temperature sensor	All Electronics <a href="http://www.allelectronics.com">www.allelectronics.com</a>
1	Peltier heating/cooling assembly	All Electronics <a href="http://www.allelectronics.com">www.allelectronics.com</a>
1	12 volt relay	All Electronics <a href="http://www.allelectronics.com">www.allelectronics.com</a>
2-3	12 volt SLA batteries	All Electronics <a href="http://www.allelectronics.com">www.allelectronics.com</a>
1	ULN2803 high voltage driver IC	SparkFun <a href="http://www.sparkfun.com">www.sparkfun.com</a>
1	Small glass beaker or tin can	Local grocery store or chemistry lab

\*Items are optional.

## VEX PELTIER HEAT PUMP EXPERIMENT



**FIGURE 4.** Note how the components for the heat pump experiment are wired. The LED lets us know when the heater is turned on/off, and the optional switch is used to start/stop the experiment.

drives the 12 volt relay from the VEX microcontroller I/O pin 11 configured as a digital output, using 12 volts for powering the relay and five volts for the control signals from the microcontroller. Make sure that the micro is connected to the relay circuit with the ground wire. Otherwise, it will not be able to drive the ULN2803 correctly.

The LM34 temperature sensor is read using the I/O pin 4 configured as an analog input. The circuit is very similar to how a stove or home heating system works. The temperature sensor is used to monitor the ambient temperature; in this case, the Peltier heating/cooling pad so that it stays close to the desired temperature or set-point.

While carrying out this experiment, I found it convenient to have a second SLA battery already charged if needed (for a total of three batteries) since one battery is needed to power the 12 volt relay. The second battery powers the heating/cooling pad. This is because the pad tends to drain the battery quickly while doing its thing. We can monitor the battery voltage while performing the experiment using a digital voltmeter. If the voltage drops below nine volts, then switch to the spare battery since it will not be able to drive three heating/cooling assemblies anymore. The microcontroller is powered with the standard VEX 7.4 volt or 9.6 volt battery.

**SAFETY WARNING:** The heat side of the Peltier pad can get very hot, so keep it away from flammable materials. For safety, use only 12 volt DC SLA batteries which are rechargeable, since an isolating 12 volt wall transformer might not be able to supply enough power to the heating/cooling assembly. When wiring the circuit using 12 volts, be sure to use heavier gauge wire that can handle the higher current loads. Otherwise, they may overheat and catch on fire.

## Thermal Control

Temperature controllers are used in consumer appliances and industrial automation for precise measurement. The SET-POINT constant is entered in the Easy C application. (Easy C is a drag-and-drop programming interface.) It is used as the threshold to energize the 12 volt relay to turn the heating/cooling assembly on or off. Another approach to enter the temperature is to use a VEX potentiometer or quadrature optical encoder. A VEX LCD display can then be used to show the set temperature and the current temperature (similar to a modern room thermostat). The temperature of the pad can be set between the minimum and maximum settings for either heating or cooling,

depending on which side of the pad is used and the application. These values are determined during calibration of the system.

The process used to control the temperature of the heating/cooling pad so that it stays close to the set-point is known as a proportional control system which is part of the PID control. If we don't monitor the set-point, we can get into a bad state known as thermal runaway where the temperature goes out of control (either too hot or too cold) when it exceeds the threshold values and can't control the temperature anymore. This situation can occur when the temperature sensor fails for some reason. When monitoring the temperature using the LM34, we can improve its accuracy and reduce the noise by averaging 20 temperature readings per control cycle (again refer to the May '12 article).

There are various ways to improve the temperature controller performance. One way is to add two more terms such as the "I" (Integral) and "D" (Derivative) terms to the proportional control equation so that it gets as close to the desired set-point in as short a time as possible. These terms help reduce the overshoot and undershoot oscillations around the threshold temperature in order to get a temperature closer to the desired set-point. (We'll cover these equations in a future article.)

To reiterate, the heating/cooling pad is turned on/off using a small 12 volt relay driven by the ULN2803 (see **Listing 2**). The 12 volt DC relay is used to switch the power on or off to the Peltier assembly when driven by the ULN2803 high voltage driver IC. It is the plastic yellow cube shown in **Figure 5**. The relay cannot be driven directly by the VEX microcontroller since the 12 volts are too high for the micro output. We can improve the heating or cooling by using convection from moving air blown by a small 12 volt

muffin fan to move the air off the hot or cold vanes and have it channeled to the tin cup using a duct made from a 2" diameter PVC tube or cardboard tube. This is commonly done on a much larger scale in HVAC for buildings and homes using forced hot air and cool air.

The fan is attached to a standard three-wire VEX motor connected to the motor block pin 1. The LM34 is connected to the analog/digital input block pin 5. The fan can be used optionally to warm or cool the air by convection when it is blown over the Peltier heater/cooler vanes.

## It's Alive!

The normal body temperature averages around 98.6°F, but variations in degrees can occur throughout the day. Too warm, and you could have a fever due to an illness. *Hyperthermia*, on the other hand, is the result of the body failing to regulate its temperature. It is usually caused by heatstroke. Any colder, and you could have serious circulatory problems. When the body temperature is abnormally low, the condition is called *hypothermia*. You can see how vital temperature is to us. We can use this apparatus at home or in the lab for our own temperature-critical experiments.

We will heat water to 98.6 degrees Fahrenheit (37 degrees Celsius) by changing the set-point constant in the EasyC Application to the 98.6. Next, place a small beaker with an ounce or two of cold water. We used a small tin can to heat the water as shown in **Figure 6**.

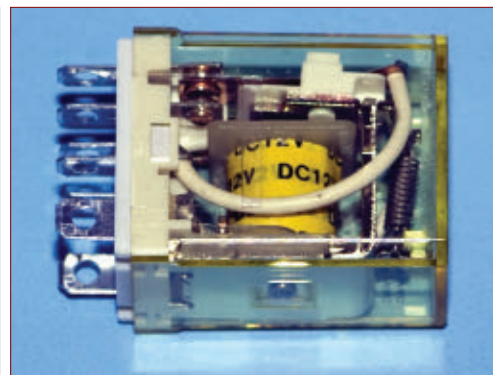
Start the experiment by switching on 12 volts from the SLA battery to power the independent Peltier heating/cooling pad relay circuit. Next, switch on the power to the pad assembly using the other 12 volt SLA battery as shown in the **schematic**. Watch for any short circuits or smoke.

You should hear the relay click on/off depending on when the EasyC application activates it to reach the selected set-point. The red LED will also turn on/off when the relay is on/off, giving you an indication when the heating/cooling pad is energized.

Note that if the beaker or glass is too large, the Peltier assembly cannot generate enough heat to warm the water to the desired set-point. In that case, just pour out some of the excess. Notice the length of time it takes to reach the set-point depends on the amount of water being heated (its mass) and the efficiency of the heating pads. Collect the data as we did above, and save it in a new text file so that we can plot it using Octave (see the Data Analysis section coming up next).

A plot of the data that was collected by the experiment was

**FIGURE 5.** The 12 volt DC relay which is used to switch the power on or off to the Peltier heating/cooling assembly when driven by the ULN2803 high voltage driver IC.

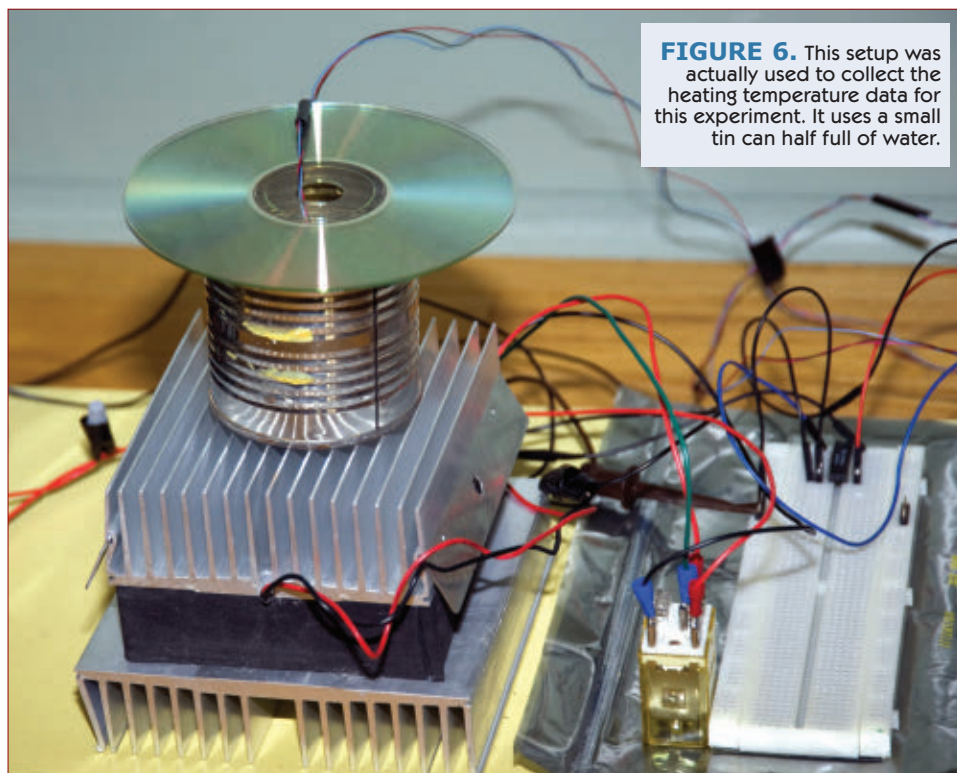


generated using Octave/Matlab and is shown in **Figure 7**. It shows how long it took to heat the water to 98.6 degrees (the life line shown in the plot in red).

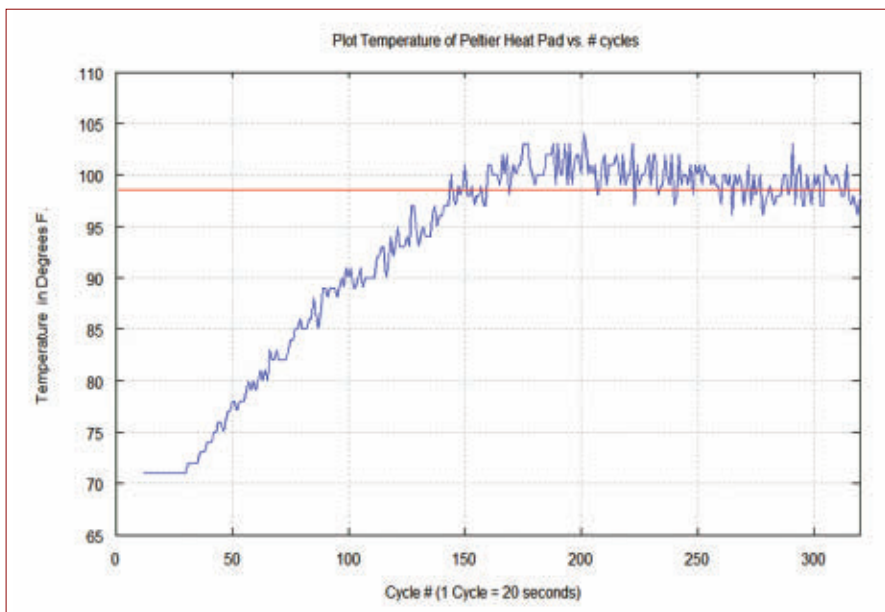
The Octave/Matlab script used to generate the plots is very easy to customize for other data analysis applications; it should also run on Mathworks MATLAB with minimal changes (if any). You can customize the labels and plot color selections. In fact, there are numerous examples for using MATLAB on the web. MATLAB has been around for many years as a mathematical modeling and simulation tool. Mathworks SIMULINK allows you to simulate a system and evaluate its performance before building it. For more information, go to the Mathworks site located at [www.mathworks.com](http://www.mathworks.com).

## VEX Peltier Cooling Experiment — The Deep Freeze

Refrigeration allows us to preserve foods for longer



**FIGURE 6.** This setup was actually used to collect the heating temperature data for this experiment. It uses a small tin can half full of water.



**FIGURE 7.** The plot of water heating to a set-point of 98.6 degrees Fahrenheit.

## Firmware

Using the proportional temperature controller example shown in **Listing 1** (which is written in EasyC Pro), we collect temperature data readings from the LM34 sensor in order to see how long it takes to reach the desired set-point. The heating/cooling unit is turned on or off by the microcontroller depending on the set-point given and the current temperature read from the LM34.

Once the set-point is reached, the micro continues to maintain that temperature. The data collected is used to generate a plot set up with cycles on the x axis vs. temperature on the y axis.

## Applications

You can use this same circuit to drive other high voltage components such as 12 volt light bulbs, motors, solenoids, etc., without overloading the VEX microcontroller which can (at best) supply five volts to digital devices and six volts for analog PWM motors to external components. Other applications for the Peltier heater/cooling pads include:

- Beverage heaters
- Portable refrigerators
- Precision temperature controlled heaters
- Laboratory equipment
- Arctic warming clothing
- Sahara Dessert cooling clothing
- Electric blankets
- Cooling blankets
- CPU coolers

## Conclusion

We discussed how temperature sensors work and what they can be used for, including proportional temperature control used in home and commercial heating thermostats, an LM34 temperature sensor, a relay, and a ULN2803 driver. This is the basic operating principle used for home and commercial HVAC and industrial control systems. We did two experiments using the LM34 temperature sensor and the Peltier heating/cooling assembly. In the first experiment, we learned what the Peltier Effect was and how it could be used to heat liquids to a specific temperature (set-point) and how it could also be used in HVAC using the VEX microcontroller. In the second experiment, we used the Peltier assembly to cool liquids.

Next time, we will cover digital sensors and what they have to offer. Until then, stay cool this summer and have fun. **SV**

periods of time. We use air conditioning in summer weather to stay cool. Swamp coolers utilize evaporative technology. Vapor-compression refrigeration is more commonly used for air conditioning. Vapor compression uses a circulating liquid (refrigerant) which absorbs and removes heat from the particular space and transfers it somewhere else.

The main advantages of a Peltier cooler (compared to a vapor-compression refrigerator) are its lack of moving parts or circulating liquid, and its small size and flexible shape (form factor). Its main disadvantage is that it cannot simultaneously have low cost and high power efficiency. Many researchers and companies are trying to develop Peltier coolers that are both cheap and efficient.

For cooling, we will mount the LM34 temperature sensor on the cool side of the pad and re-run the experiment using the same setup shown in **Figure 6**, except flip the assembly so that the cooling vanes are on top and the heating vanes are on the bottom. Use a high temperature ceramic dish to support the Peltier heating/cooling assembly. Fill a small tin can or Styrofoam cup with an ounce or two of cold water. We can only cool a very small amount of water just a few degrees, but you should be able to detect the cooling temperature rate using data analysis.

The cooling side of the Peltier assembly is not quite as efficient as the heating side, unfortunately. Make sure you cover the tin can with a lid to insulate it. Note that the temperature changes will not be as dramatic as they are with heating, and it will take longer to reach the set-point (for example, the freezing point of water — 32 degrees Fahrenheit). Another idea is to use a small 12 volt DC fan or PC fan to blow the cool air from the cooling vanes into a Styrofoam cup using a cardboard or plastic duct, simulating a refrigerator or air conditioner.

A challenge to the reader is to see how much you can drop the temperature of, say, an ounce of water using some other kind of insulating material and enclosure (to hold the water and the LM34 temperature sensor). Use the same analysis techniques including plotting the resulting data using Octave; compare it to trying to cool the water in a tin cup.

```

#include "Main.h"
void main ( void )
{
    long Resistance = 0;
    // Assuming a 10K Thermistor
    double Temperature = 0.0;
    // Scaled temperature reading in Degrees
    long Cycle = 0; // Number of cycles
    float Period_In_Seconds = 0;
    long Scale_Factor = 1; // Scale Factor
    long Offset = 300; // Start at 0.3 seconds
    int Period = 0;
    // Measure temperature every n seconds
    double SetPoint = 98.6;
    // Set water temperature to 98.6 degrees
    double Sum_Temperature = 0.0;
    // Compute average temperature
    SetDigitalOutput ( HEATER , HEATER_OFF ) ;
    // Turn off the heater using ULN2803 high
    // voltage driver
    SetDigitalOutput ( HEATER_LED , LED_OFF ) ;
    // Turn Off the Heater LED indicator
    Cycle=0 ; // Initialize the temperature reading
    // cycle count (every n seconds)
    Sum_Temperature = 0.0 ;
    // Initialize the temperature sum
    while ( 1 ) // Main control loop for temperature
    // experiment #1
    {
        Temperature_Sensor_1 = GetAnalogInput ( LM34 ) ;
        // Read the temperature from the LM34 solid
        // state temperature sensor

        Temperature = ConvertToFahrenheit(Temperature
        _Sensor_1) ;
        // Convert raw temperature to degrees Fahrenheit
        Sum_Temperature += Temperature ;
        // Accumulate the temperature sum for 20
        // readings
        if ( Cycle %20 == 0 )
        // Compute average temperature and display
        // every 20 Cycles
        {
            PrintToScreen ( "Cycle = %d" , (
            int)Cycle/20 ) ;
            Temperature = Sum_Temperature / 20.0 ;
            // Compute the average temperature for
            // 20 cycles
            PrintToScreen ( " Temperature F = %ld" ,
            (long)Temperature ) ;
            // Display the converted temperature sensor
            // 1 reading
            //Temperature = ConvertToCelsius
            (Temperature) ;

            // Convert temperature in degrees Fahrenheit
            // to degrees Celsius
            //PrintToScreen ( " Temperature C =
            //%ld\n" ,
            (long)Temperature ) ;
            // Display the converted temperature sensor
            // 1 reading
            //Wait ( 1000 ) ;
            // Wait a bit between temperature readings
            Sum_Temperature = 0.0 ;
            // Initialize the temperature sum
            if ( Temperature < SetPoint )
            // Compare temperature to the set-point of
            // 98.6 degrees Fahrenheit
            {
                PrintToScreen ( " - HEATER ON\n" ) ;
                SetDigitalOutput ( HEATER , HEATER_ON ) ;
                // Turn on the heater using ULN2803 high
                // voltage driver
                SetDigitalOutput ( HEATER_LED , LED_ON ) ;
                // Turn On the Heater LED indicator
                //Wait ( 5000 ) ;
                // Turn on heater for 5 seconds
            }
            else
            {
                PrintToScreen ( " - HEATER OFF\n" ) ;
                SetDigitalOutput ( HEATER , HEATER_
                OFF ) ;
                // Turn off the heater using ULN2803 high
                // voltage driver
                SetDigitalOutput ( HEATER_LED , LED_
                OFF ) ;
                // Turn Off the Heater LED indicator
                //Wait ( 5000 ) ;
                // Turn off heater for 5 seconds
            }
        }
        Cycle++ ; // Increment the temperature reading
        // cycle count (every n seconds)
        Wait ( 50 ) ;
        // Wait a bit between temperature readings
    }
}

```

**LISTING 1. The Peltier heating/cooling is turned on or off by the VEX microcontroller, depending on the set-point given and the current temperature read from the LM34.**

```

% Plot of Temperature of Peltier Heat Pad vs. # cycles (1 Cycle = 20 seconds)
% temp1 = Peltier Heating/Cooling assembly (hot side)

load vex_temp_exp_3.dat
who

% Extract temperature data collected from Peltier Heating/Cooling assembly and plot it
data = [temp1(:,1) temp1(:,2)];

% Generate a line indicating the Setpoint of 98.6 degrees Fahrenheit (Body Temperature)
for i=1:320;
data(:,3) = 98.6;
endfor;

plot (data(:,1), data(:,2), 'b', data(:,3), 'r'), xlabel("Cycle # (1 Cycle = 20
seconds)"),ylabel("Temperature in Degrees F. "),title("Cycle # (1 Cycle = 20 seconds)"),axis([0.0
320.0 65.0 110.0]), grid on;

```

**LISTING 2. The Octave script used to generate the plot. It is very easy to customize it for other data analysis applications, and should also run on MATLAB with minimal changes (if any).**

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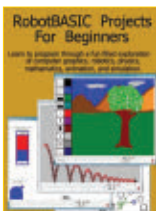
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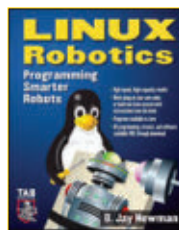


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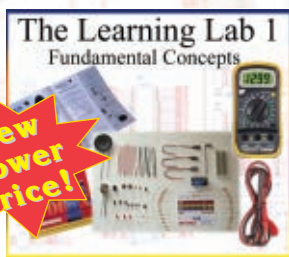
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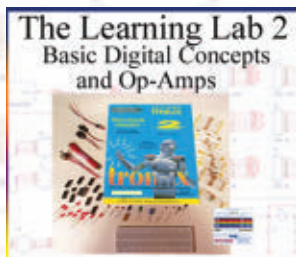
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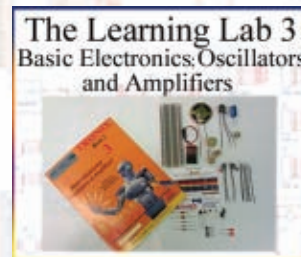
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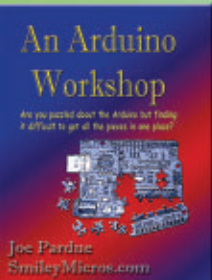
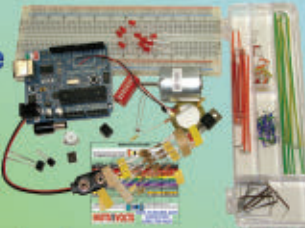
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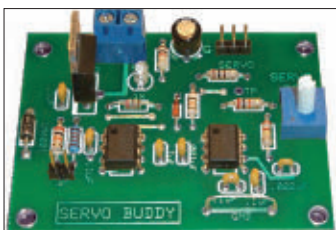
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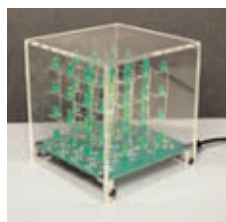
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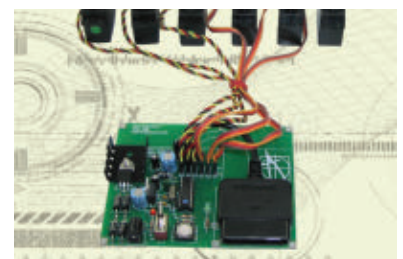


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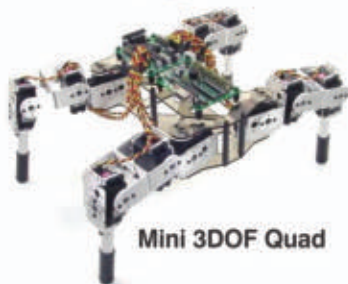
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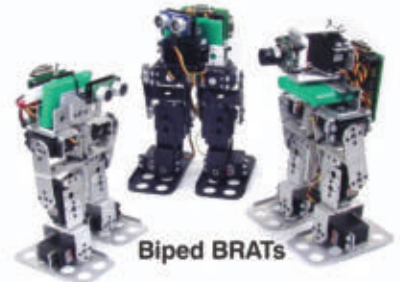
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# Twin Tweaks

BYCE WOOLLEY & EVAN WOOLLEY



**THIS  
MONTH:**

**Big Trouble in  
the Little  
Dohyo**

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THE COBRA MINI SUMO CHASSIS KIT.

[www.servomagazine.com/index.php?/magazine/article/july2012\\_TwinTweaks](http://www.servomagazine.com/index.php?/magazine/article/july2012_TwinTweaks)

For the past few months, we've pitted sensors against each other in honor of the upcoming Olympic games, which will finally kick off at the end of the month. This time, we thought it would be a great idea to take a look at one of the most time-honored robotic events of all time: the mini Sumo competition. In particular, we have the opportunity to look at a starter kit perfect for the aspiring mini Sumo master: the Cobra Mini Sumo Chassis from Fingertech Robotics. To get the chassis ready for action, we would have to find our inner Frankenstein and track down a suitable brain. We hoped the result would be more *Eva* and less *Young Frankenstein*. With our soldering iron instead of scalpel, we set about our surgical saga.

## Rise of the Cobra

The mini Sumo competition is a classic robotics event featured in everything from the massive RoboGames to small local events. The object of the event is simple: Push your opponent out of the ring. The field (or dohyo, to use the historical terminology) is generally a black circle with a white outline, with a radius that varies depending on the weight class of the competitors (for the mini Sumo weight class, the diameter of the dohyo is 77 cm). Sumo robots generally must comply with width, length, height, and weight requirements (for the mini Sumo weight class, the robot can have a max length of 10 cm, a max width of 10 cm, and there is no height limitation; the weight maximum is 500 g). Other than that, the design possibilities for Sumo bots are pretty wide open (except you can't have flamethrowers or magnets or jammers or anything too crazy). Sumo is more a study in optimization than wild off-

the-wall designs. While combat robots might brandish saws, jaws, and spinning drums, the sweeter science of Sumo has a more focused objective than wanton destruction. Pushing your foe out of the ring effectively requires a specific combination of traction, a low center of gravity, and a low wedge. As much as we personally dislike wedges in combat robotics, they are an intuitive choice for mini Sumo, and the similarity of the basic robot designs makes for an interesting comparison of ideas. Who has the best traction? The best motors? Who was able to save weight on their batteries to more optimally distribute it with ballast? We always like to think of the excitement of combat robotics as inherent in the opportunity to test your ideas against someone else's, and Sumo competitions provide plenty of opportunity for optimization.

Mini Sumo, then, is in many ways much more rigid and traditional than combat robotics events. That is not to say that creativity is not rewarded, but rather that the focus of the creativity is somewhat narrower. The relative simplicity of the basic Sumo challenge means that the event is accessible for anyone with a working knowledge of anything ranging from LEGO Mindstorms to custom PCB printing. The Cobra mini Sumo chassis from Fingertech seeks to help jump-start that creativity and provide a springboard for success in the dohyo.

When we first assessed the Cobra chassis, it was natural for us to compare it to the other member of our robotic menagerie designed for mini Sumo competitions. The Mark III robot from Junun Robotics has been a frequent guest star in many of our columns, even though we almost never seem to use it for its intended purpose. Now, we finally had a chance to appreciate it

for its Sumo capabilities.

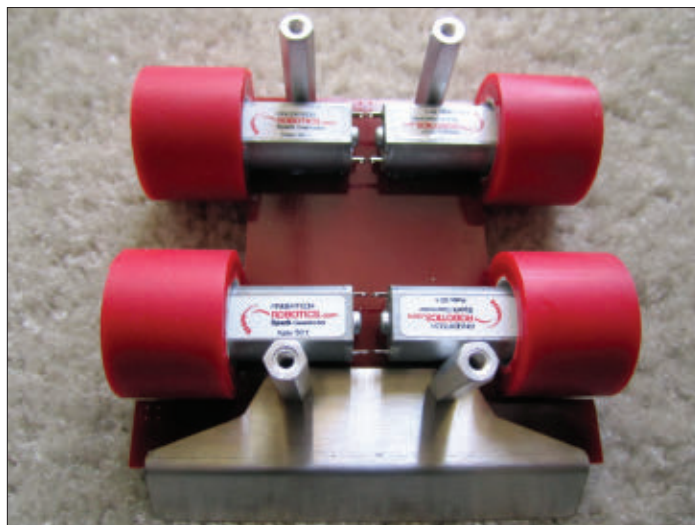
The Mark III has always served us admirably in the past, but comparing it to the sleek Cobra must have given our trusty companion feelings similar to those of Woody upon first meeting Buzz Lightyear. Instead of standard size full rotation servos, the Cobra features four Spark gearmotors with a mighty 50:1 gearbox. The Mark III finds traction with rubber wheels on plastic hubs. The Cobra uses A20 polyurethane wheels which give the bot the highest traction available to a Sumo competitor. The Mark III wheels attach to the servos with traditional hubs. The Cobra chassis is also direct drive, and the motor contains three internal supports to dispel any fears about leaving the wheels unsupported. The Mark III makes do with a wedge made of thin plastic, while the Cobra sports a wedge fashioned from 0.020" thick angled stainless steel. All of that is not to say that the Mark III is an unimpressive bot. It would certainly run circles around (and inevitably push out of the dohyo) Gog III – the mini Sumo robot Evan made from LEGO Mindstorms for an event in 2004. The Cobra chassis is quite obviously designed for the serious competitor, intent on directing the tinkerer to continue its commitment to optimal design.

We made a few other observations about the Cobra chassis before we took to wiring it up. Something immediately apparent upon picking up the chassis is that it has some weight to it – 333 grams, to be exact. The max allowable for mini Sumo (under RoboGames rules) is 500 grams. Now, 167 grams might not seem like a lot of wiggle room, but with a judicious battery selection that shouldn't be an issue. If it really was, however, you could remove the source of most of the weight: a steel ballast attached to the underside of the Cobra's Garolite base.

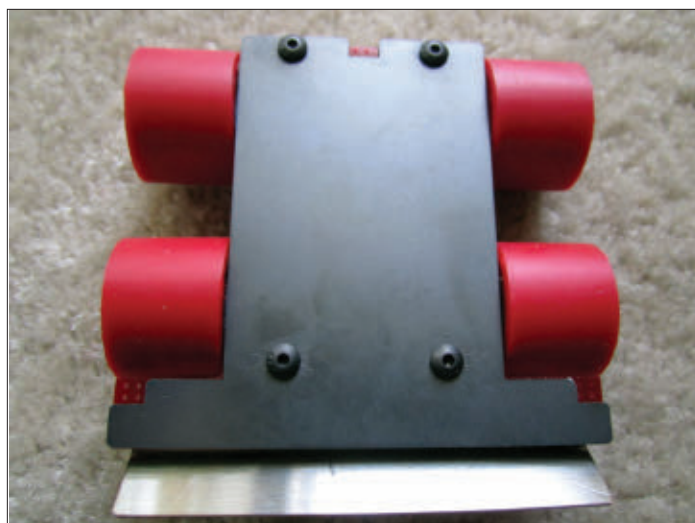
The ballast is attached with four screws that also attach to four standoffs meant to support your PCB of choice. The ballast is very nicely machined, and reminded us of our FIRST robotics days when one of the first tasks completed by Team 1079 was to design the floor of the robot with all of the main mounting holes included so that it could be machined in one beautiful piece. Such attention to detail was evident in the Cobra's ballast – it included cutouts meant to accommodate three QRD1114 infrared sensors to allow the bot to stay within the confines of the dohyo.

The cutouts are positioned at the right and left edges of the front and the middle of the back, and the Garolite base includes corresponding holes for the pins of the sensors. Even without any sort of additional casing, the thickness of the ballast adjacent to the mounted sensors is more than enough to keep the sensors safe from being bent around.

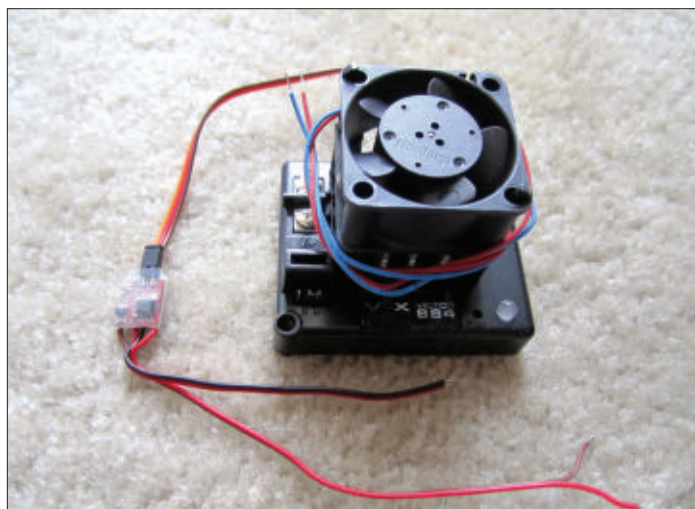
Finally, something that might seem somewhat incongruous with the meticulousness of the rest of the chassis is that the motors are mounted onto the Garolite base with glue. Mounting with glue can be problematic for several reasons – the vagaries of the semi-liquid adhesive mean that the motors might not set in ways that are perfectly level or parallel. We also had some initial concerns



A CLOSER LOOK AT THE CHASSIS.



THE BALLAST, WHICH LEAVES SPACE FOR SENSORS AT THE FRONT, SIDES, AND MIDDLE BACK.



THE TINYESC SPEED CONTROLLER IS TINY INDEED.



THE RHINO LIPOLY BATTERY PACK.

about the shear strength of the glue – if a powerful opponent with particularly strong motors hit just right, we were afraid that this Cobra might just find its mongoose. Our fears, however, seemed unwarranted because the motors on our kit appeared very level, parallel, and thoroughly connected.

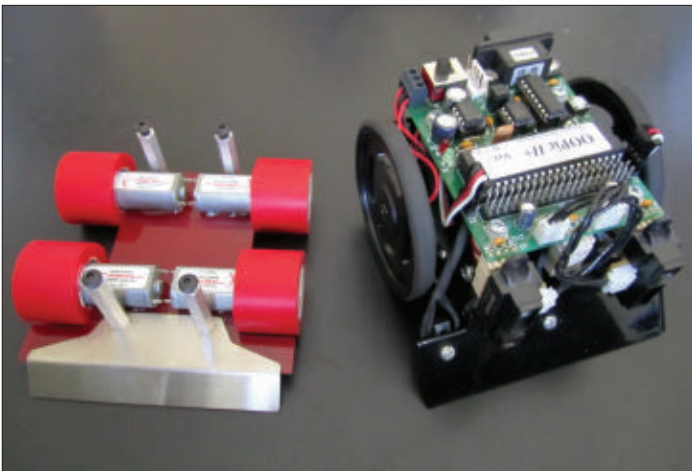
### I Feel the Need for Speed Controllers

The Cobra chassis obviously holds a lot of promise for mini Sumo greatness, but that doesn't mean the path to victory is an easy one. The chassis is an impressive starting point, but it is only a chassis. The robot needs a power source, a brain, and a way to control the motors. Fingertech ably supplies two of those components: the battery and speed controllers. As far as batteries go, we were able to get our hands on a Rhino 11.1V, 360 mAh lithium polymer battery pack. Now was not the time to get too excited about power sources, however, because first we needed to sort out all of the electronic bits that needed power.

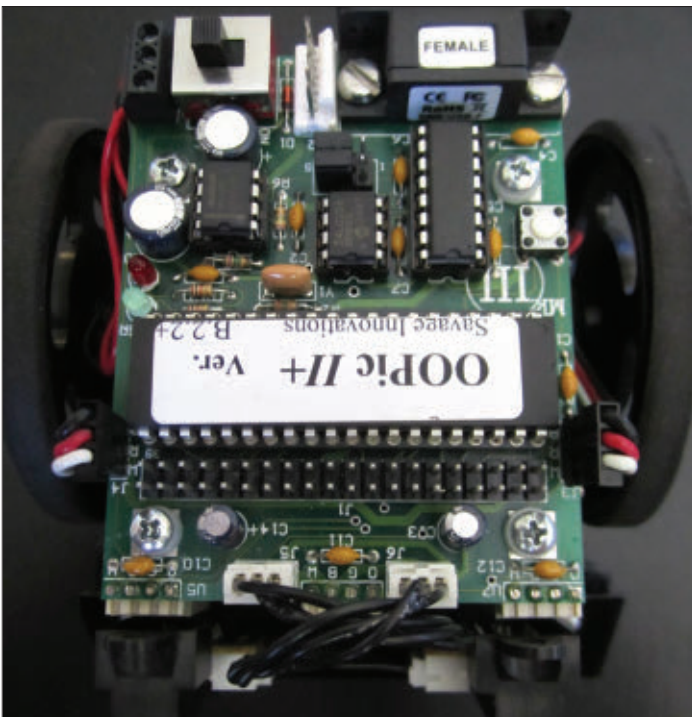
The other major components we got from Fingertech were electronic speed controllers. We're most used to dealing with Victor 884 speed controllers which are a favorite of ours both with combat robots and FIRST robots. Victor 884s, however, are not exactly the most feasible choice for a mini Sumo robot. Thankfully, Fingertech has the perfect solution with the aptly named TinyESCs. The TinyESCs are miniscule speed controllers with a PWM output, leads to go to the motors, leads to the battery, and a built-in battery eliminator circuit. The compact unit also includes a jumper to help calibrate the motors when they're being radio controlled. The TinyESC can handle 6.5V to 36V, up to 1.0A continuous and 2.8A peak. In other words, plenty for any mini Sumo robot.

The battery eliminator circuit is an interesting addition that could be very useful for weight-conscious roboticists. Admittedly, it is not something that we had worked with before because most of the robots we've built did not have weight requirements so strict that eliminating the receiver battery would be hugely beneficial. For weight-watching applications like RC airplanes and lightweight robotics, battery eliminator circuits are sort of like a bot's version of the lap band. For radio-controlled projects, the radio receiver often needs a separate battery, usually something more modest than what's needed to power the motors or main electronics. The battery eliminator circuit allows the receiver to be run off of the bot's main battery by scaling down the voltage and current so as not to blow out the receiver.

Since the motors on each side of the chassis are controlled as a set, two TinyESCs are all that's needed to control a mini Sumo robot. No TinyESCs are required if the user's PCB of choice is equipped with motor drivers, but the brain we were eyeing was as driverless as a DARPA Grand Challenge competitor. There are two options for wiring the motors to the TinyESCs: they could be wired in series or in



TRANSPLANT PATIENTS.



THE MARK III BRAIN.

parallel. Wiring them in series has the advantage of being cleaner by using shorter wires and avoiding the necessity of branching loops. The huge disadvantage of a series hookup, of course, is that it halves the power of the motors by acting as a voltage divider. Competitive Sumo players are as demanding of “more power” as Tim the Tool Man Taylor, so a series hookup was pretty much out of the question. Wiring up the motors in parallel requires a few more wires, but is certainly worth the trouble to power the motors appropriately.

Whenever we wire up robots, we try to hold ourselves to a level of professionalism that started with our combat and FIRST robots. We like to use connectors and route the wires cleanly — something that was instilled in us by our main mentor (and our Dad), and something he practiced as the electrical process leader at Cosworth Racing back in the day. We prefer connectors and sockets to soldering connections in place because connectors are clean and they allow for quick disassembly (cannibalization?) of electronic guts which is something we seem to do with some frequency. So, our grand plans with the Cobra chassis were to find some appropriately diminutive slide-on connectors so that the TinyESCs could be easily removed in case we ever had another weight-conscious project.

Taking another look at the chassis made us rethink this approach. The motor leads are excruciatingly close together — something fairly inevitable given the strict width requirement under mini Sumo rules. The leads are not touching, but they sure look like they want to. And while we consider ourselves decently skilled at soldering, it would take a steady hand not to short the wires with an errant glob of solder. There is an easy solution, however — bend the leads to give your nervous fingertips some quite literal wiggle room. That is just what we did, but even so we were concerned about whether connectors would have enough clearance — the rigidity of the connector extends beyond the motor lead, and given the spartan space requirements we thought that we would bite the bullet and solder with care.

We soldered the TinyESCs to the motors without incident, and kept everything reasonably clean with some strategically placed heat shrink. If we were actually preparing the bot for competition, we would have been far more conscientious about the length of the wires. In fact, we would have changed many things about how we charmed the Cobra to life, but our trials and tribulations led in the end to an instructive parable. It all really began when we started nailing down the power requirements for the bot ...

## With Great Power Requirements Comes the Great Responsibility of Wiring Everything Up Correctly

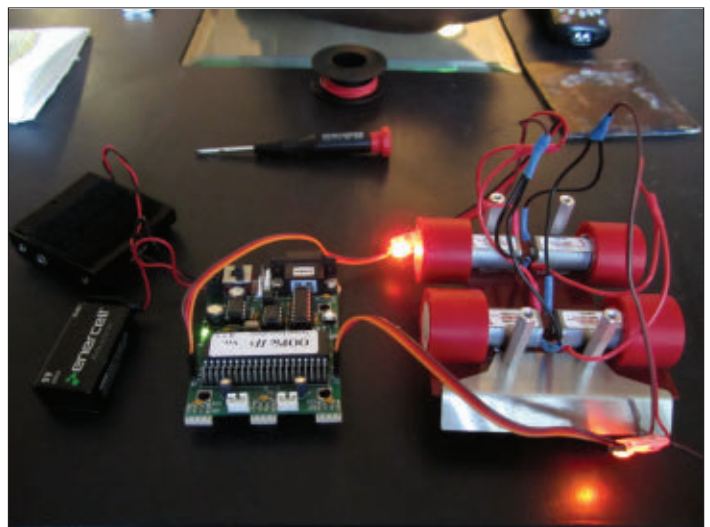
Now, we were pretty much at the Scarecrow stage of the project, and all our bot wanted was a brain. The choice of brain is up to the roboticist. You could devour the brain



TOO CLOSE FOR COMFORT!

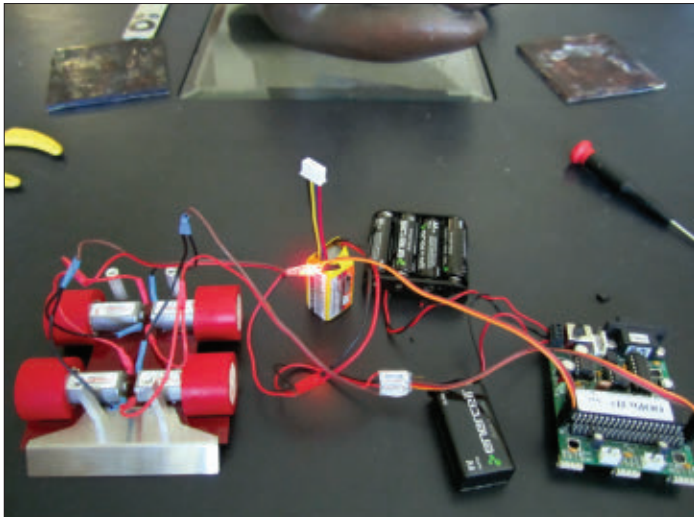


WIRING UP THE MOTORS.

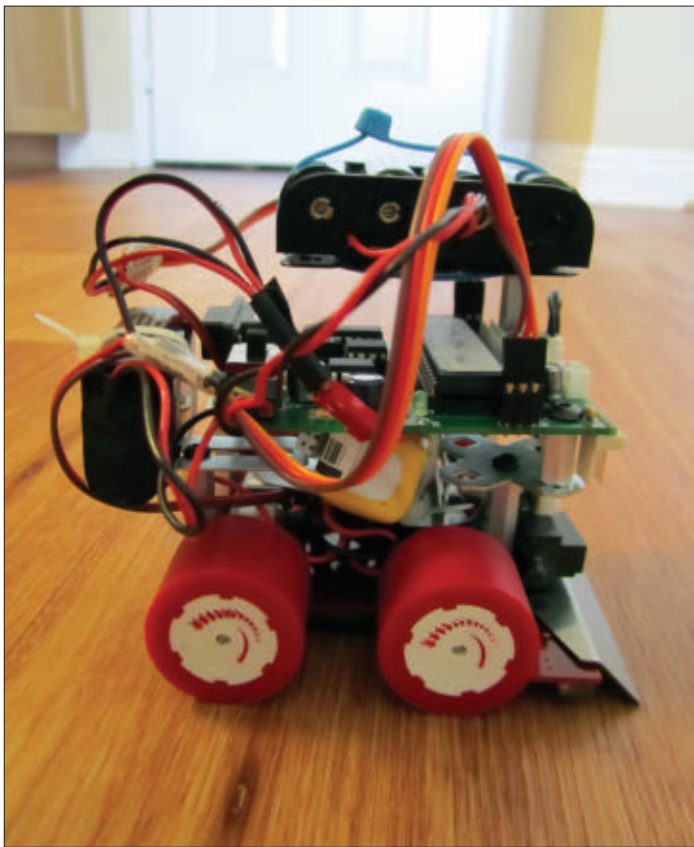


INITIAL TESTING.

from another project like a hungry zombie, or you could put together your own brain on a breadboard, perf board, or custom PCB. We wanted to see if the controller board from the Mark III would work, given that the Mark III was in a similar line of work.



MEETING THE POWER REQUIREMENTS.



A BATTERY OF BATTERIES.

The controller board came off of the Mark III easily enough — just a few screws for structural support, and then we had to disconnect the electronics. What could have been a tedious ordeal filled with solder suckers and braid was refreshingly easy because all of the sensors were socketed.

Connecting the motors to the brain would be easy enough. The controller board features two PWM inputs that match up perfectly with the connections from the

RECOMMENDED WEBSITE

[www.fingertechrobotics.com](http://www.fingertechrobotics.com)

SPECIAL THANKS TO

Kurtis Wanner

TinyESCs. This, however, is where things got a bit complicated.

The Mark III is powered by two separate battery packs: a 9V battery and a battery pack of four AA batteries. The four AA pack is the power for the servos, and the 9V is for the board electronics. These battery packs do not exactly meet the voltage requirements for the mighty Spark gearmotors. Also, the Mark III controller board cannot even handle the current draw for DC motors. The good folks at Junun Robotics have additional boards capable of picking up that slack, but if we did want to use the Mark III basic controller board for competitive mini Sumo an entire additional board would not be ideal from a center of gravity standpoint.

To confirm our suspicions about power (the Spark motors ostensibly have an operating voltage as low as 3V, though low voltages are not good for the motors), we tried hooking up the components with the existing Mark III battery packs. The LEDs on the TinyESCs flickered to life, but the motors did not activate despite the presence of a simple Sumo program on the controller board. Resigned to our fate, we examined our options about getting the components the power they needed.

Our apparent problem was that the motors were not getting the power they needed to operate. The seemingly simple solution was to use the Rhino LiPoly battery pack to power the entire board. This, however, threatened several disadvantages. First, the wiring would be a tedious chore. The power sources connect to the Mark III via a small terminal block with three connections. One is for the ground, two are for power. One of the terminals is meant to supply between 4.8V and 9V (for the servo power), while the other is meant to source 6V to 16V (for the electronics on the board). Our first instinct was that if we were going to use the LiPoly cell to power the whole robot, we would need to add a resistor between the LiPoly pack and the 9V max terminal to reduce the voltage from the pack. Then, we realized that the terminal was for the servos that were no longer used on the bot, but it made us ponder an interesting problem.

Many of the controller boards that an aspiring Sumo champion might consider using with the Cobra chassis could have differential power requirements that are not ideal for a Sumo bot. If a simple controller board lacks some voltage regulation, powering the entire bot with a powerful pack like the Rhino could threaten to fry delicate electronics. Some controller boards might have small back-up batteries for their microcontrollers that — without additional voltage regulation — could be vulnerable to the

unpleasant fate of electrical death when hooked up to a bigger battery.

Fortunately, the Mark III does have some voltage regulation for the board electronics which explains why it can handle batteries ranging from 6V to 16V. The terminal block, however, holds in the battery leads with set screws — not exactly something that meshes well with the JST connector on the Rhino LiPoly pack. For short-term convenience and to illustrate the risks of divergent power requirements, we stuck with the Mark III battery packs and used the Rhino LiPoly packs only for the motors.

### Brain Freeze

When we finally got all of our batteries wired up and turned on the bot for a bench test, we were thrilled that the motors sprang to life. Now all that was left was putting everything together in a reasonably compact fashion.

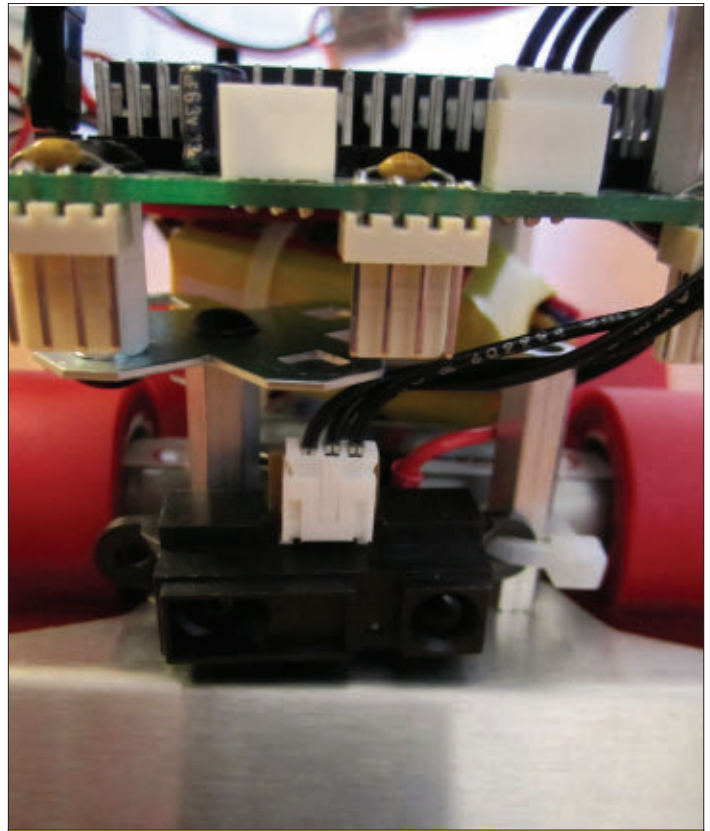
As if the power requirements headache was not enough of a signal, when we went to actually put the disassembled robot together we were met with another clue that the Mark III controller board is not exactly the ideal brain to use with the Cobra chassis. The Mark III controller board has four holes in the PCB to accommodate screws that fasten to standoffs. The Cobra chassis has four standoffs. What seemed like a perfect fit turned into a cruel joke when we went to check the alignment of the standoffs and the holes in the controller board PCB. The horizontal and vertical spacing of the standoffs was different than the holes on the PCB. A few cannibalized VEX parts, however, were all that was needed to get the PCB on nicely. The space between the motors was the perfect place to stash the compact and lightweight Rhino battery.

The bot even had some nice additional places for some sensors. We borrowed one of the Mark III's infrared rangefinders to give the Cobra some forward-looking vision. When we had the bot together, we were excited to see it in action, and we were very impressed with the crazy strength of the motors. The Cobra pushed around some of our other bots with ease, and we're sure it could have taken on the Mark III — if the Mark III still had a brain.

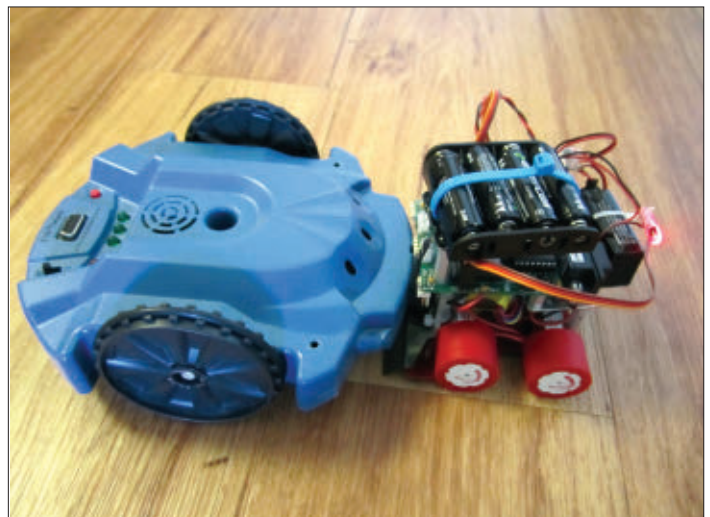
### Snake Charmed

Did our completed robot look ridiculous lugging around three separate battery packs, a towering monument of excess weight, and poorly managed power requirements? Yes indeed, but even with an odd construction that looked like a competitive game of Jenga the chassis had no problem staying balanced and pushing around foes.

Overall, we do think the Cobra mini Sumo chassis is an impressive product. It is a fantastic starting point for intrepid competitors really looking for an edge inside the dohyo. To really get the most out of the kit and take advantage of all it offers, roboticists should be committed to disciplined design — maintaining the footprint of the



EYE OF THE COBRA.



FIGHTING OFF A FEROCIOUS FOE!

robot, staying cognizant of power requirements to use just one small battery, and (as simple as it sounds) using a PCB that doesn't require any crazy framework. A more disciplined approach on our behalf could have resulted in a much more compact bot, but it is reassuring to know that the robot is more than capable of carrying around shelves of components. The chassis would even make a nice base for an experimental sensor platform, and at just under \$120 it makes a feasible option for a range of projects well beyond the hallowed confines of the dohyo. **SV**



# Then and NOW

## Sensors For Mobile Robots — Part 3

b y T o m C a r r o l l

The last two months, I've been referencing Bart Everett's sensor book from 1995 — *Sensors for Mobile Robots* — a book that, in my opinion, should be on every robot experimenter's bookshelf. Everett's book emphasizes just how critical the need and use of sensors is for successful robot designs. His book not only describes how they work but which ones to use and how to use them. Though it was published 17 years ago, almost all of the types and technology involved are still appropriate for today's robot designs.

In this series on sensors for mobile robots, I have referenced Everett's book so much because it has always been an inspiration for me. The Navy and Everett's robots

have certainly advanced quite a bit since he first started building his series of 'Robart' robots as test platforms. Not only has onboard computer intelligence advanced, but the associated sensors have made amazing leaps in technology. Robots rely quite a bit on advanced mechanical and power systems, but it is sensor technology coupled with computer science that has created the amazing robots that we see in the forefront of today's military actions and surveillance.

As robot experimenters, most of us want to keep abreast of the latest advances in any science and engineering aspect of our creations. We certainly don't have the seemingly unlimited funding like the military, so we must rely on the best that we can find for the lowest cost. I have tried to present the best solutions in sensor technology that I could find from robot manufacturers and suppliers while keeping most products below \$100. A lot of the products that I have reviewed have been in the \$10-\$50 range, except for the MaxBotix weather-proof sonar at \$100 and the Parallax laser range finder at \$130. This month, I will discuss some unique sensors — most of which happen to be from Parallax, and range in price from \$6 to about \$60. I do encourage you to look at the great products from all the robot-specific companies.

### Localization: Where Am I?

Once a robot leaves the confines of our workshop area, another problem begins to become evident: The robot



FIGURE 1. Mark Curry — winner of the RoboMagellan contest at Robothon 2010.

needs to know where it is. Robots like the ones that compete in the Seattle Robotics Society's (SRS) Robo-Magellan events move in large multi-acre areas and cannot rely just on visual and sonic sensors with a short maximum range. The SRS Robo-Magellan is a robotics competition emphasizing autonomous navigation and obstacle avoidance over varied, outdoor terrain. Robots have three opportunities to navigate from a starting point to an ending point, and are scored on the time required to complete the course with opportunities to increase the score based on contacting intermediate points.

**Figure 1** shows the 2010 winner, built by Mark Curry. I have had the enjoyable opportunity to help judge the SRS Robo-Magellan events at Seattle, and have been amazed at the many different designs and techniques used by the contestants. GPS is the key 'sensor' used, though odometry, vision, and object detection are also important.

## GPS — the Global Positioning System

The GPS concept was being finalized in 1973 when I joined the Rockwell division in Seal Beach, CA to help operate an antenna test range. We placed large GPS satellite mockups equipped with the antenna arrays on a long robot-like arm in order to manipulate the satellite in different ways to determine the antenna's radiation pattern. We tested mainly at the L1 frequency of 1575.42 MHz and the L2 frequency of 1227.6 MHz.

GPS is basically a simple concept with some complex mathematics involved. One of the most critical parts of the system is a series of extremely accurate cesium beam atomic clocks, with four on the satellites and less accurate rubidium clocks used in key ground receiver stations. A GPS receiver that is either on the ground, in a vehicle, missile, or airplane calculates its position by precisely timing the signals sent by the satellites at a 20,200 km or 12,600 mile 'half geosync' orbit. Each satellite continually transmits messages that include the time the message was transmitted and the satellite's position at the time of the message transmission; a minimum of three satellites (but usually four) must be visible to the receiver to determine accurate position information.

One of the earliest military backpack GPS receivers (shown in **Figure 2**) weighed many pounds and cost as much as a Ferrari. Compare that to today's handheld devices that weigh ounces and cost as little as \$30. I remember a demo at the Rockwell plant of such a backpack device where the soldier could accurately locate himself within 30 feet. That was amazing. Nowadays, with Wide Area Augmentation System (WAAS) corrections —



**FIGURE 2. Early GPS manpack receiver.**

originally developed for the FAA — GPS can be used by surveyors to ascertain a position anywhere on the globe within inches. Cell phones, iPads, and many other devices use tiny GPS chip sets embedded in them to give accurate localization information to consumers. Use your search engine to read more about the C/A public code and the military encrypted P/Y signals, nuclear detonation detection, code subframes, and the many updates on the latest satellite constellations.

## GPS for Our Robots

Some of the GPS receivers used on Robo-Magellan robot contestants have been handheld units with the digital data fed to the robot's onboard microcontroller. Most, however, have used dedicated GPS modules that are designed to be

embedded within a robot or piece of equipment. The Parallax VPN1513 GPS receiver module and antenna shown in **Figure 3** is such a module that has been used on many robots. The VPN1513 uses the very popular SiRF Star III chipset capable of tracking up to 20 satellites. The VPN1513 has a Propeller co-processor for an easy interface with any microcontroller. The Propeller is also fully reprogrammable and includes access to all 32 I/O pins, allowing the GPS receiver module to be used as a stand-alone device.

Operating from 4.5V to 12V at 80 mA (5V), the VPN1513 uses an MCX board-mounted connector for the antenna connection that is a snap-on variation similar to the more familiar SMA threaded sub-miniature connector. The antenna has a nine foot cable that seems a bit long for the typical robot. I managed to step on it while testing the module outdoors when it was attached to a PropBOE board that was then attached to my netbook (I bent some pins on the module).

The small 1.85" x 1.80" board communicates via an



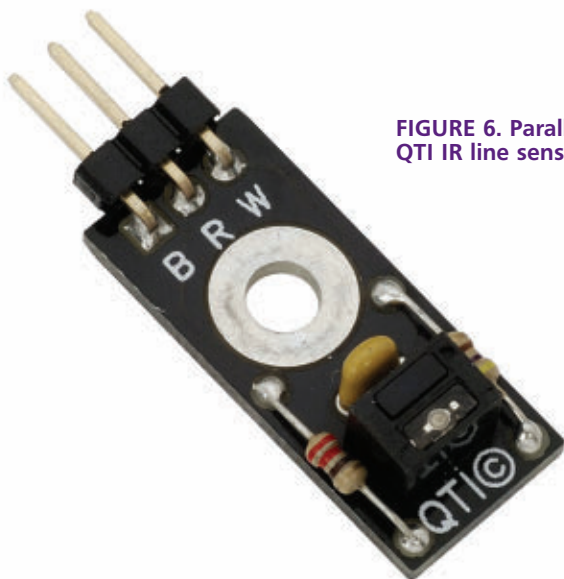
**FIGURE 3. Parallax GPS receiver/antenna module.**

**FIGURE 4. BU-353USB GPS receiver from RobotShop.**



asynchronous serial 9600 bps interface, and a BASIC Stamp 2 demo code is available at the Parallax website. I did manage to have it operate with the PropBOE and it was fairly sensitive on a very cloudy day. The stated sensitivity is -159 dBm which is pretty impressive. It is a great GPS addition to any robot.

I tested another GPS receiver (shown in **Figure 4**) from the RobotShop. Quite frankly, this unit is more adept at mounting on a vehicle's roof with the magnet under the receiver and patch antenna, but it can also be used with robots. As with the Parallax module, this system made by USGlobalSat uses the SiRF Star III chipset for its BU-353 GPS receiver and it is attached to a computer via a USB connector. It is completely self-contained and waterproof, and has a five foot cable. It has the same -159 dBm sensitivity as the Parallax unit, and the onboard LED indicates when the receiver is on, or a 'position fixed' when it is flashing. It is compatible with the Microsoft "Streets & Trips" program, and I found several good pages of information at the USGlobalSat site (though it took me a bit of playing around with the program to get my computer to finally work).



**FIGURE 6. Parallax QTI IR line sensor.**

**FIGURE 5. Parallax ColorPAL sensor.**



## Sensing Other Phenomena: Color and Light

Considering that there are literally thousands of phenomena of all categories that one might desire to detect and measure, I'll just cover a few of the more interesting available to the robot experimenter. One happens to be the determination of color that many small robots have used to detect and select M&Ms, Easter eggs, candies, and similar colored objects in contests. The Parallax ColorPAL shown in **Figure 5** is a miniature color and light sensor utilizing the Taos light-to-voltage converter and an RGB LED. To sense color, the 1.72" x 0.90" x 0.65 sensor uses the LED "to illuminate a sample, one color component at a time, along with a broad-spectrum light-to-voltage converter to measure the light reflected back. The amount of light reflected from the sample under illumination from each of the red, green, and blue outputs of the LED can be used to determine the sample's color."

I tested the sensor on the Board of Education of a BOE-Bot equipped with a BASIC Stamp 2 — a very typical application platform for many contests and classroom exercises. I did find that it can be over-powered by sunlight and even the strong incandescent lighting that I was using to photograph the robot, but shading the sensor from overhead lighting was simple and effective. The sensor detects broad-spectrum ambient light with sensitivity down to 44  $\mu\text{W}/\text{cm}^2$  with a 24-bit color output signal for a simple serial connection.

The color detection and generation details are handled by an onboard microcontroller, and an onboard EEPROM is available for saving custom color detection and generation programs. The sensor operates from 5 VDC with a single serial asynchronous open drain output.

An even simpler light sensor is the Parallax QTI sensor

shown in **Figure 6**. QTI stands for *Q* = Charge, *T* = Transfer, *I* = Infrared. It is an infrared emitter/receiver that is able to differentiate between a dark surface (with low IR reflectivity) and a light surface (with high IR reflectivity). These little sensors can be very handy for line following, maze navigation, or sensing the outer rim of a Sumo ring. Wiring options allow it to be used digitally for fast black/white line following, or as an analog sensor to detect different shades of gray. A daylight filter is built into the sensor.

The QTI uses an external microcontroller to measure an onboard capacitor's charge decay rate that is proportional to the charge transfer through the IR phototransistor detector. As the returning IR reflection is non-focused, it is usable on all types of smooth or rough surfaces. The daylight filter helps isolate only the returning emitted IR signal. I did find that the use of a small shield (I used a curved and taped-together piece of cardboard for the test) helps to isolate the reflected IR signal. The tiny (1.25" x 0.37") QTI operates on 5 VDC and interfaces nicely with an Arduino, BASIC Stamp, or Propeller-based microcontroller.

## Atmospheric Sensing

I'm going to step away from direct mobile robot related sensing and concentrate a bit on the sensing of the air, atmospheric pressure, humidity, and certain gasses that might be present in the air around a robot. One measurement that would not normally be ascribed to a surface mobile robot is atmospheric pressure and humidity. An AUV might need such a sensor or even a near space high altitude balloon experiment package, or possibly a robot on which the builder wanted to install a weather station.

Before discussing actual sensors, let me describe several methods of determining humidity. Most home humidity devices are not very accurate because humidity measurement requires a bit of air circulation at the sensor site. Too much or too little air flow results in inaccurate results. Some crude wall-mounted weather stations actually use a horse hair or similar moisture-collecting thread that shrinks or lengthens according to the ambient humidity, which is then hooked to a revolving needle for indication purposes.

The very best way to determine humidity is by what is known as a 'sling psychrometer' — two side-by-side thermometers mounted on a ruler-sized stick, hooked to a swivel handle and slung in a circle by hand. A classic version is shown in **Figure 7**. One of the thermometer bulbs has a gauze sock or sleeve wrapped around it that is dipped into distilled water prior to measurement. When the two thermometers pass rapidly through the ambient air, the



FIGURE 7. Sling psychrometer.

'wet bulb' will become cooler due to evaporation of the water, whereas the 'dry bulb' will stay at the ambient temperature. The lower the humidity, the cooler the wet bulb.

The user then refers both temperature readings to a chart to determine the humidity and dew point. Some manufacturers have encased the two thermometers with the wet bulb dipped in a water reservoir, and a small electric fan that moves the air through the cavity to create evaporation. For some reason or another, many of these non-sling electric models are also called 'sling' psychrometers.

Needless to say, this more accurate (but messy) technique is not preferable for robot or remote AUV/ROV measurements. The Parallax Sensirion temperature/humidity sensor shown in **Figure 8** is a great dual sensor for robot experimenters. It is a smart sensor for both humidity and temperature, and is mounted in a tiny eight-pin DIP 0.43" x 0.49" package that incorporates an analog-to-digital interface. All that your microcontroller has to do is read the humidity and temperature values through the two-wire digital serial interface; only the bi-directional data line requires a pull-up. The only math necessary is a simple scale and offset. The SHT1x has a resolution of 0.01 degrees C and relative humidity with a resolution of 0.03% worst-case

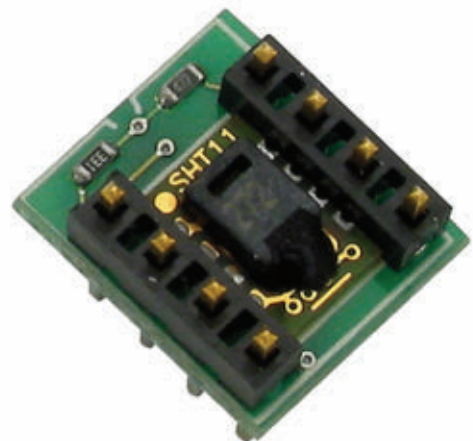
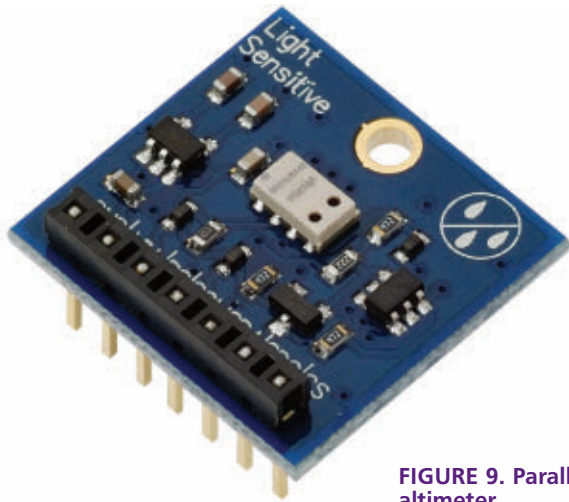


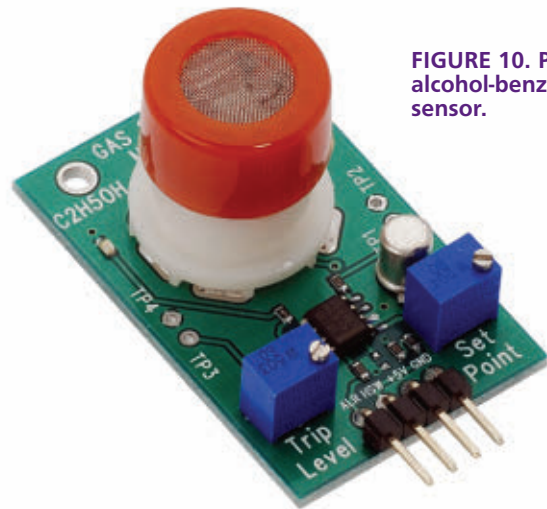
FIGURE 8. Parallax Sensirion SHT1x.



**FIGURE 9.** Parallax altimeter.

temperature accuracy is better than  $\pm 1$  degrees C in the 20 degree range. The relative humidity section is similarly accurate:  $\pm 3.5\%$  in the 20% to 80% range. I found that it responded to humidity and temperature changes more rapidly than the two weather stations I have at home. I had an accurate thermometer to verify the temperature but relied on my weather station's humidity readings. The board typically operates at 5 VDC at a very low 6  $\mu$ A.

Parallax has another module that measures altitude quite accurately that also incorporates a thermometer. Their altimeter module shown in **Figure 9** has an altitude resolution of 20 cm or about eight inches. That's not too bad when you can measure up to 120,000 feet at near space altitudes. I didn't get a chance to test this one out, though I've read about its use in several applications. The module includes a high linearity barometric pressure sensor and a high resolution temperature output, allowing implementation of an altimeter/thermometer without any



**FIGURE 10.** Parallax alcohol-benzene sensor.

additional sensors. Different operation modes allow the user to optimize for conversion speed or current consumption. The module is designed for use with a large variety of microcontrollers with different voltage requirements.

The thermometer section has a resolution of  $< .01$  degrees C in a range of  $-40$  to  $+85$  degrees C, and a pressure range of 10–1,200 mbar which amounts in near space to a deep mine. Operating from 3.3 to 6.5 VDC and supporting I<sup>2</sup>C and SPI communications (20 MHz), it's a great dual instrument package for UAVs and high altitude balloons.

## Gas Sensors

Now, I'd like to review a series of gas sensors that Parallax offers. They are actually bringing out a new line of gas sensors that are all-in-one modules but have the identical characteristics of the modules I'll discuss here. Unlike the sensors I've covered so far, these sensors do not give discrete values or percentages/parts per million, but rather are used as concentration limit detectors. For instance, the C<sub>2</sub>H<sub>5</sub>OH (alcohol/benzene) gas sensor module shown in **Figure 10** can detect a preset level as an alcohol breathalyzer, but cannot determine percentages of alcohol above or below the set point.

I found these five gas sensors quite unique, and it was most interesting to test them. I used different levels of a gas flame on my stove, as well as on my barbeque, my breath, dry ice, rubbing alcohol, and even decaying compost. Some worked very well and others not so much. Some gasses triggered two sensors, but I was able to set a trigger level for all five sensors for a single type of gas. The actual sensor interconnection is done through a four-pin SIP header and requires two I/O pins for the microcontroller.

These gas sensor modules use gas sensors from Hanwei Electronics. When their internal heating elements are activated, these sensors respond to their specific gas by



**FIGURE 11.** Parallax CO sensor.

reducing their resistance in proportion to the amount of that gas present in the air exposed to the internal element. On the gas sensor modules, this is part of a voltage divider formed by the internal element of each gas sensor and potentiometer R3 (set point). The output of this voltage divider is fed into the non-inverting inputs of the two op-amps on the LT1013 dual op-amp IC. Op-amp A is configured as a buffer with unity gain and is used to provide a non-loaded test point for the signal voltage at TP1 (+) and TP2 (-). As with the above alcohol sensor, the CO sensor is also a resistive device.

The signal voltage is also being fed into op-amp B which is configured as a comparator that gets its reference voltage at the inverting input from potentiometer R4 (trip level) and is also available at TP3 (+) and TP4 (-). Individual sensor module elements are available to use with an interfacing module, and individual polarity is not important as they are essentially resistive devices. Much greater detail about interfacing and calibration is available at the Parallax website. The C<sub>2</sub>H<sub>5</sub>OH gas sensor module operates at 5 VDC at 250 mA with the heater on and 60 mA with the heater off — a PWM programming arrangement that you must code into your microcontroller. This and the other gas sensor modules come with a tiny adjustment screwdriver for the trim pot and interface nicely with a BASIC Stamp or similar 5 VDC microcontroller.

Parallax has a CO (Carbon Monoxide) gas sensor module that's shown in **Figure 11**. This technology has been around for home-type alarm systems for a while and is quite inexpensive. It can be set to trigger at CO concentrations as low as 500 ppm. It has similar interfacing properties but uses a different heating cycle for purging and sensing with the Hanwei Electronics element. The heater is supplied with 5 VDC (at 165 mA) to purge the sensor element for 60 seconds and then is ramped down to 1.4 VDC (at 50 mA) for the sensing phase. Example source code is provided for the BASIC Stamp 2 module at <http://obex.parallax.com>. CO alarms are popular and sometimes a requirement for today's homes. They have been hacked by many experimenters.

The Parallax CO<sub>2</sub> (Carbon Dioxide) gas sensor module shown in **Figure 12** has the same four-pin SIP header and is compatible with most microcontrollers. This sensor actually uses a gold element to detect a pre-set CO<sub>2</sub> level. The power requirements are 6.5-15 VDC at 160 mA in the sense mode (with the heater on) and 2 mA in standby. This higher voltage requirement must be taken into consideration in a robot's design.

The calibration procedure is a bit tricky for this module, so you should refer to the downloadable information on the Parallax site. I had to play with it a bit, but I did check out two different points that I had set with the calibration procedure. I used dry ice for the higher test concentration. You will find the technical specifications about the Hanwei sensor and the chemical reactions quite interesting, not only for this sensor but all gas sensors.

The interface includes one TTL compatible input (HSW)

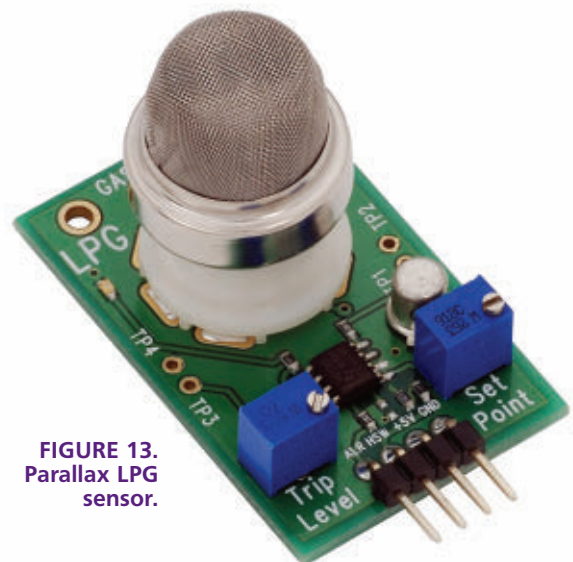
**FIGURE 12.**  
Parallax CO<sub>2</sub>  
sensor.



and one TTL compatible output for the alarm. I feel that the extra cost of this module is due to the gold elements used inside.

Parallax also has two other gas sensors: the CH<sub>4</sub> (Methane) gas sensor and the LPG (Propane) gas sensor which is shown in **Figure 13**. Methane is not usually a concern around the typical home, so I used decaying compost as my test source. Methane's detection might come in handy since it is flammable and could present a hazard.

The power requirement for both devices is 5 VDC at 160 mA. Propane is more prevalent around a home and careless use of propane appliances and heaters can be extremely hazardous. Detection by a mobile robot would be useful where propane exists in a home, RV, or enclosed building. Testing and setup was quite simple, and very helpful documentation for all these gas sensors is available at the Parallax site.



**FIGURE 13.**  
Parallax LPG  
sensor.



FIGURE 14. Parallax sensor sampler.

## Final Thoughts

There are numerous sensors applicable for use on robots, such as those in the Parallax sensor sampler shown in **Figure 14**. Strain gauges and force sensors can replace whiskers and switches as contact sensors and measurement of forces on a robot's arm. Linear transducers, rotary speed measurements, numerous types of encoders, and even current sensors to measure motor loads can be used in our robots to give them (and us) a better understanding of their world and the outside world. The many suppliers of robots and robot-related parts advertising in this magazine have great websites to steer you to the right sensor choices.

There are several unique types of sensors that I'd like to discuss in the near future: the several variations of the Microsoft Kinect, the Microsoft SoundWave being developed for laptops, the Asus Xtion, and the PrimeSense game sensor and their PS1080 system-on-a-chip. These sensors cannot only recognize your voice and face, but will allow you to control their motions and actions by your voice and hand movements. They are the latest step in allowing your robot to recognize you, and for you to easily control your robot. Happy robot building! **SV**

Tom Carroll can be reached at [TWCarroll@aol.com](mailto:TWCarroll@aol.com).



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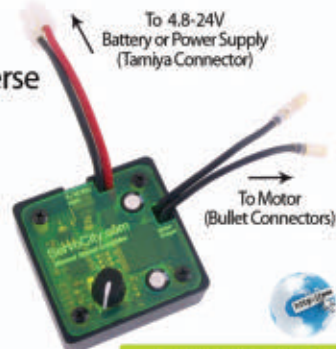
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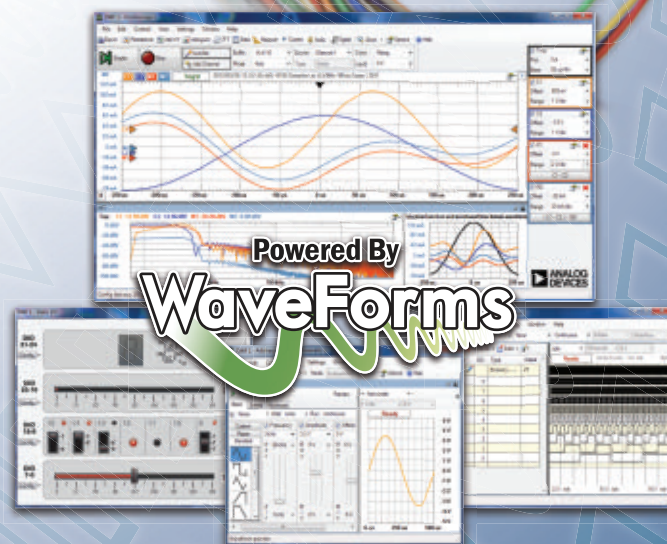
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